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TEST AND EVALUATION OF TAPE TRANSPORTS AND TECHNIQUES FOR AIRBO--ETC(U)
JUL 77 O E BASSETTE, R B RESEK, L W FERBER F33615-75-C-1145

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TEST AND EVALUATION OF TAPE TRANSPORTS AND TECHNIQUES FOR AIRBORNE HIGH DATA RATE DIGITAL RECORDING

410 472

RCA Corp.,
INFORMATION PROCESSING & RECORDING SYSTEMS
GOVERNMENT COMMUNICATIONS SYSTEMS
CAMDEN, NEW JERSEY 08102
AUGUST 1976

JULY 1977

Technical Report AFAL-TR-76-131

FINAL REPORT MAY 1975 TO APRIL 1977

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This technical report has been reviewed and is approved for publication.

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(6) Test and Evaluation of Tape Transports and Techniques for Airborne High Data Rate Digital Recording,

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Test, evaluation and analysis were made on two ~~RCA~~ magnetic tape transports. These data were compared against the Air Force requirements to record Digital Data generated by an Airborne Synthetic Aperture Radar Set/Analog to Digital Converter/Duty Cycle Compression System for (AN/UPD-X). An Airborne Digital Tape Transport configuration is proposed based on these data and analysis. Performance and performance margins are given or estimated. Magnetic tape evaluation data is also analyzed and a "tape drop-out" model is presented with a proposed Error Detection and → next page

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20. ABSTRACT (Continued)

Correction (EDAC) system which will allow very high bit packing densities (two billion bits per cubic inch) at low bit error rates with uncertified magnetic tape.

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FOREWORD

This report was prepared for the Air Force Avionics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433, under contract F33615-75-C-1145. The technical monitor of the program was Mr. S. Rostocki, RWI-1. The research in this report includes the period from 20 May 1975 to 29 April 1977 and the report was submitted by the authors April 1977.

This report was prepared by O. Bessette, R. Resek, L. Ferber

RCA Corp.
Information Processing and Recording Systems
Government Communications Systems Division
Camden, New Jersey 08102

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1.0 INTRODUCTION

1.1 DIGITAL TAPE TRANSPORT

This report describes tests, evaluation and analysis performed on two RCA supplied magnetic tape transports. This effort was performed to advance the development of an airborne 2-inch tape transport for recording digital data at rates of 250 Million bits/second for side looking radar applications, e.g., UPD-X. This effort included environmental test and evaluation and in particular, the vibrational requirements imposed by the MIL-E-5400 airborne specification.

1.1.1 BACKGROUND

Current radars use film as a data storage media and the recorders have all the disadvantages of film: limited dynamic range, non-instant replay and wet chemical processing. The SAPPHIRE engineering development effort will, with appropriate preprocessing, apply digital magnetic tape recording to recon radar for the first time. SAPPHIRE will use the AN/APD-10 Radar and obtain data rates of 35-40 megabits per second with a total storage capability of 10^{10} bits. Future reconnaissance radars, such as the AN/UPD-X, will require 1 to 5 times the SAPPHIRE data rates and ten times the storage capacity. Currently available digital recording capabilities cannot meet these requirements.

1.1.2 STATE-OF-THE-ART

This contractor has achieved in-track bit-packing densities of over 25,000 bits/inch at track densities of over 80 tracks/inch on 2-inch tape. This yields an area packing density of 2×10^6 bits/square inch, and has demonstrated 240 mb/sec. on unit 1. The result of this tape utilization and data rate improvement is more record time, or higher data rate, or a small recorder, or a combination of the above. This technique, called High Density Multitrack Recording (HDMR), is the result of six years of contractor effort in Government sponsored research and development programs. HDMR technology

utilizes critical and unique techniques which are proprietary to the contractor in several areas. Examples:

- Unitized (single piece) head fabrication
- Elimination of playback equalization
- Elimination of analog circuit adjustments

1.1.3 SUMMARY OF CONTENTS

This report contains test data from two RCA supplied magnetic tape transports and related analysis and conclusions. All tests were performed on available units, with available test equipment, data processing, and read/write electronics. The hardware used was a composite of subsystems developed on prior and current High Density Multitrack Recording (HDMR) programs, both in-house and government sponsored. In particular, the breadboard (Unit #1) tape transport controller and the digital data processing electronics were available from prior RCA R&D and NASA feasibility study programs, and the new design HDMR transport (Unit #2) was just recently completed under in-house R&D funds and was designed specifically with the Air Force requirements in mind. Test data from the first unit was valuable in aiding the design of Unit #2. Test Data from Unit #2 is valuable for assessment of the HDMR potential for the Air Force applications. Unit #2 is a coaxial reel design which will accommodate 10,000 feet of tape for 20 minutes at 250 Mb/s with minimum installation footprint and volume.

Other test and evaluation data included in this report pertains to magnetic tape and magnetic head performance, and supplementary to this, head-to-tape performance as described by the tape drop-out profile. This drop-out profile is used as the driving function for an error detection and correction (EDAC) scheme which will ensure an operational system performance of 10^{-6} BER (bit error rate).

The major divisions of this report are:

(1) Test Data on Breadboard Tape Transport (Unit #1)

(2). Test Data on New Transport Design (Unit #2).

(3) Test Data on Tape and Heads.

(4) Tape Dropout Model and Error Detection and Correction.

(5) Analysis of Results and Projected System.

Table 1-1 following the Statement of Work in a cross reference to specific paragraphs.

1.2 STATEMENT OF WORK

STATEMENT OF WORK
TEST & EVALUATION OF AIRBORNE DIGITAL TAPE TRANSPORT

1.0 Objective: The objective of this effort is to test, evaluate and analyze contractor developed and supplied airborne magnetic tape transports. This effort will advance the development of airborne 2-inch tape transports for recording digital data at rates to 250 MBits/second for side looking radar applications.

2.0 Scope: The scope of this effort will be to test, evaluate and analyze airborne tape transports and determine their application to contractor developed high data rate digital recording devices and techniques for Air Force use. This includes environmental test and evaluation but does not require recording equipment purchase or delivery.

3.0 Background: Current radars use film as a data storage media and the recorders have all the disadvantages of film: limited dynamic range, non-instant replay and wet chemical processing. The SAPPHIRE engineering development effort will, with appropriate pre-processing, apply digital magnetic tape recording to recon radar for the first time. SAPPHIRE will use the AN/APD-10 Radar and obtain data rates of 35-40 megabits per second with a total storage capability of 10^{10} bits.

Future reconnaissance radars, such as the AN/UPD-X, will require 1 to 5 times the SAPPHIRE data rates and ten times the storage capacity.

Currently available digital recording capabilities cannot meet these requirements.

3.1 State-of-the-Art: This contractor has achieved in-track bit-packing densities of over 25,000 bits/inch at track densities of over 80 tracks/inch on 2-inch tape. This yields an area packing density of 2×10^6 bits/square inch, which is at present about four (4:1) times better than competitive techniques. The results of this tape utilization and data rate improvement is more record time, or higher data rate, or a smaller recorder, or a combination of the above. This technique, called High Density Multi-track Recording (HDMR), is the result of four years of contractor investment in Government-sponsored research and development programs. The technology utilizes critical and unique techniques which are proprietary to the contractor in several areas. Examples are:

- Unitized (single piece) head fabrication
- Elimination of playback equalization
- Elimination of analog circuit adjustments

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4.0 Technical Requirements/Tasks: The purpose of this effort is to determine the application of the proprietary section 3.1 techniques to airborne digital side looking radar recording requirements.

4.1 Tests and Analyses: The contractor shall perform the following tests on the contractor furnished brassboard transport under the specified environmental conditions and analyze the results. Table 1 is a list of the tests and analyses to be performed. The abbreviated efforts denoted by an "A" are defined as "a test or analysis of less than all conditions stated, but at least one".

4.1.1 Flutter and Jitter: These tests will determine the time base stability of the tape transport.

4.1.1.1 Input: The recorded signal will be a 20 bit NRZ word at 2.143 Mbps consisting of 10 "ones" followed by 10 "zeroes" thus generating a 107 KHz squarewave.

4.1.1.2 Measurements: Jitter will be measured on a dual trace oscilloscope by observing the time displacement of the signal being played back and a reference signal identical to the signal that was recorded on the tape. Flutter will be measured using a frequency discriminator and a chart recorder. A flutter signature will be taken in the laboratory environment as reference data for diagnostic comparisons.

4.1.2 Skew: This test will determine the track-to-track jitter versus track position.

4.1.2.1 Input: Same as in 4.1.1.1.

4.1.2.2 Tracks: Three tracks, not necessarily adjacent, close to the center of the tape will be used as the reference for determining skew. At least two tracks on both sides of center and extending to near the edge of the tape will be monitored and compared to the center-track reference to determine skew.

4.1.2.3 Measurements: Data will be taken on the track-to-track jitter versus track position.

4.1.2.4 Skew Profile: A skew profile will be generated indicating the peak to peak skew across the two inches of tape referenced to the center of the tape. Trends in skew data as a function of reel tape load will also be reported.

4.1.3 Tracking: This test will determine the ability of the transport to maintain head-to-tape alignment along track.

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4.1.3.1 Input: An NRZ "1010 . . ." pattern at 2.143 Mbps will be recorded.

4.1.3.2 Measurement: An amplitude modulation detector will be calibrated to measure the loss in signal level due to mistracking. Signal loss (in db) will be reported as a function of reel tape load as well as overall mistracking effects.

4.1.4 Signal to Noise Ratio (SNR) Test:

4.1.4.1 Input: Same as Paragraph 4.1.3.1.

4.1.4.3 Measurement: SNR measurements will be taken with a RMS reading voltmeter. Both selective (3 KHz slot) and wideband SNR measurements will be made. Measurements will be made on at least three tracks.

4.1.5 Bit Error Rate (BER) Test: This test is a quantitative measure of tape drop outs. A dropout is defined as a loss in playback signal of greater than 6 db, random in occurrence and less than 200 μsec duration at a tape speed of 86 ips.

4.1.5.1 Input: An NRZ one million bit pseudo random word at 2.143 Mbps will be recorded on at least three tracks.

4.1.5.2 Measurement: An amplitude detector and a time discriminator will be used to count tape dropouts and classify their size. The BER at the decoder output will be measured and BER trends or fluctuations will be reported.

4.1.6 Tape Type: At least two types of tape will be evaluated with respect to SNR, BER and dropouts. The effects of using preconditioned or cleaned tape as opposed to uncleaned (virgin) tape will also be studied.

4.1.7 Temperature/Altitude Tests: Tests 4.1.1 through 4.1.5 will be performed for at least the four conditions listed below:

Test No	Temperature	Altitude	RH
1	+5°C	Sea Level	30%
2	-5°C	Sea Level	30%
3	+50°C	Sea Level	30%
4	+30°C	70,000 Feet	30%

4.1.8 Vibration Tests: The contractor will measure BER, Tracking, Skew and Flutter while vibrating the tape transport in three orthogonal axes. The goal is to achieve vibration levels of MIL-E-5400 curve IA to 2000 Hz.

4.1.9 Tape Storage Tests: Evaluate tape that has been stored at elevated temperatures and high relative humidity or for long periods of time.

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4.1.10 Error/Performance Model: Develop, via analyses of results of above tasks, an error/performance model of the tested equipment and selected tape. Propose Error Detection and Correction (EDAC) techniques if required. Tradeoff tape cleaning versus EDAC.

4.1.11 Environmental Effects on Performance: Investigate/analyze throughout the above items the effects of environment on the performance and life and the system margins required in such areas as:

a. head-to-tape interface
b. bit-error-rate
c. head and tape life
d. tracking
e. skew

4.2 Baseline Equipment Configurations: Determine via analyses of above items optimum baseline equipment configurations including but not limited to:

a. track width

b. tracks/inch

c. package dimensions

d. tape speed

e. transport

5.0 Deliverable Items

5.1 Data in accordance with Exhibit A, DD Form 1423.

5.2 Test and Evaluation Review: Two complete oral reviews of the results of the program shall be presented to Air Force personnel at the location designated by the contracting officer. The presentations shall be organized to cover, as a minimum, each of the items listed in Section 4. One review will cover the mid-point of the program and the second shall cover the final results of the program.

6.0 Contractor Supplied Equipment

The contractor will supply the following hardware to be used during the study program.

a. One (1) Brassboard (2 inch by 2000 ft. tape) transport.

b. 14 Channels of HDMR electronics to encode, record, decode each channel.

c. 164 track HDMR head.

PURCHASE REQUEST
NO. FY11757511007

DATE: 74 Aug 30

TESTS		MEASUREMENTS					ANALYSIS					
RECORD CONDITIONS	INFORMATION	FLUTTER	SKEW	TRACKING	SNR	BER	BER PROFILE	D.O. PROFILE	SKEW PROFILE	TRACKING PROFILE	PERFORMANCE DEGRADATION	EDAC ERROR MODEL DETERMINATION
STANDARD CONDITION T = 25^{0}C NO VIBRATION	10^6 BIT PSEUDO RANDOM WORD NRZ "1010..." NRZ 10 "ONES" 10 "ZEROES"	* US P-P ABS.	* US P-P VS. TRACK SPACING VS. TRACK POSITION	* % AM	* RMS/RMS N.B. & W.B.	* ERRORS/ SEC.	* BER VS. REEL POSITION	* D.O. SIZE VS. REEL POSITION	* SKEW VS. REEL POSITION	* TRACKING VS. REEL POSITION	* % CHANGE VS. #PB PASSES	* RANDOM AND BURST ERROR MODEL
VIBRATION (MIL-E-5400/11A) 1. LIGHT 2. INTERMEDIATE 3. GOAL		*	*	*	*	*	*	A	*	*	A	A
TAPE TEMPERATURE 1. -5^{0}C 2. +5^{0}C 3. +30^{0}C @ 70KFT 4. +50^{0}C		A	*	*	*	*	A	A	*	*	*	A
TAPE CHOICE 1. 3M971 2. DU PONT CRO		A	A	A	*	*	*	*	A	A	*	*
TAPE STORAGE 1. LONG TIME 2. HIGH TEMP. 3. HIGH R.H.		A	A	A	*	*	*	*	A	A	*	*

NOTE: ALL PB AT STD. CONDITION T = 25^{0}C NO VIBRATION 30% R.H.

* - COMPLETE EFFORT
A - ABBREVIATED EFFORT

TABLE 1: REQUIRED TESTS, MEASUREMENTS AND ANALYSES

TABLE 1-1. REQUIRED TESTS, MEASUREMENTS AND ANALYSIS CROSS REFERENCE

	Flutter	Skew	Tracking	SNR	BER	BER Profile	D.O. Profile	Skew Profile	Tracking Profile	Performance Degradation	EDAC Error Model	Jitter
Std. Conditions	1 (1) 2.4.3 (1) 2.4.3 (2) 2.5.2 (2) 2.5.7	2 (1) 2.4.5 (2) 2.5.4	3 (1) 2.4.6 (2) 2.5.5	4 2.6.6	5 (1) 2.4.1 (1) 2.4.2 (2) 2.5.1 (2) 2.5.6	6 (1) 2.7.1 (2) 2.8.1	7 (1) 2.7.7 (2) 2.8.6	8 (1) 2.7.5 (2) 2.8.4	9 (1) 2.7.6	10 2.9.1	11	I (1) 2.4.4
Vibration	12 (1) 2.4.3 (1) 2.4.8	13 (1) 2.4.5 (1) 2.4.8 (2) 2.5.4	14 (1) 2.4.6 (1) 2.4.8 (2) 2.5.5	15 2.7.7 2.8.6	16 (1) 2.4.2 (2) 2.5.1 (2) 2.5.6	17 (1) 2.7.2 (1) 2.7.8 (2) 2.8.1	18A (1) 2.7.7 (2) 2.8.6	19 (1) 2.7.5 (1) 2.7.8 (2) 2.8.4	20 (1) 2.7.8	21A (1) 2.7.8 (2) 2.8.7 2.9.2 2.9.3	22A	II (2) 2.5.3 (2) 2.5.7 (2) 2.8.3
Tape Temp. & Alt.	23A 2.6.2	24 2.6.4	25 (1) 2.4.6 (+35°C) 2.6.5	26 2.6.6	27 2.6.1	28A 2.6.1	29A 2.6.1	30 2.6.4	31 (1) 2.6.6 2.6.5	32 2.6	33	III 2.6.3
Tape Choice	34A 2.6.2	35A 2.6.4	36A 3.2.4	37 3.2.3 3.3.3	38 2.6.1 3.4	39 2.6.1	40 2.6.1 3.3.1	41A 2.6.4	42A 2.6.5	43 3.2.2 3.2.5 3.2.6	44 3.5 4.0 (AU) All	IV 2.6.3
Tape Storage	45A	46A	47A	48	49	50	51	52A	53A	54	55	V

← 5.0 (ALL) →

A = Abbreviated Efforting   All Others = Complete Effort

1.3 CONTRACT DATA REQUIREMENTS

CONTRACT DATA REQUIREMENTS LIST

ATCH NR ____ TO EXHIBIT A
TO CONTRACT/PR FY11757511007
CATEGORY ____
SYSTEM/ITEM ____
CONTRACTOR ____

1. Sequence Number	2. Title or Description of Data / 3. Subtitle	4. Authority (Data Item Number)	5. Contract Reference	6. Technical Office	7. DD250 Req	8. App Code (A)	9. Input to IAC (X)	10. Frequency	11. As of Date	12. Date of 1st Submission	13. Date of Subsequent Subm/Event ID	14. Distribution and Addressees (Addressee – Regular Copies/Repro Copies)	15. Total	16. Remarks
A001	Program Schedule	DI-A-3007/M-103		AFAL/RSP	LT	N		ONE/R		30 DAC		AFAL/RSP 1/0; AFAL/RSM 1/0; 4950/PMES 0/0; ACO 0/0	2/0	Revisions may be reported with Item A002. Letter of Transmittal only to 4950/PMES and ACO.
AC02	R&D Contract Status	DI-A-3002/A-113		AFAL/RSP	LT	N		MTHLY		40 DAC	Every 30 lays there-after.	AFAL/RSP 2/0; AFAL/RSM 1/0; 4950/PMES 0/0; ACO 0/0	3/0	Letter of Transmittal only to 4950/PMES and ACO.
A003	Technical Report (Final)	DI-S-3591/S-117/m		AFAL/RSP	DD	AD		ONE/R		See 13	Draft: 165 DAC Final: 210 DAC	Draft: AFAL/RSP 4/0; Final: AFAL/RSM 50/1	54/1	One (1) copy of final report shall be delivered unbound. Distribution Statement will be assigned by AFAL after review of report.
A004	TRACE (Technical Report Analysis, Condensation, Evaluation)	R&D-MI-AFAL		AFAL/RSP	LT	N		OTIME		165 DAC		AFAL/RSP 1/0; AFAL/TSR 1/0	2/0	

PREPARED BY: Stanley J. Rostocki
STANLEY J. ROSTOCKI, AFAL/RSP, 54906
DATE: 74 Aug 07

APPROVED BY: Richard Jennewine 30 Sep 74
RICHARD JENNEWINE, ACTG 665A PROGRAM MGR
DATE: 74 Sept 27

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PAGE 1 OF 1 PAGES

CONTRACT DATA REQUIREMENTS LIST

ATCH NR ____ TO EXHIBIT ____

TO CONTRACT/PR FY11757511007

CATEGORY ____

SYSTEM/ITEM PROGRAM 665A

CONTRACTOR RCA

1. SEQUENCE NUMBER	2. TITLE OR DESCRIPTION OF DATA / 3. SUBTITLE		6. TECHNICAL OFFICE			10. FREQUENCY	12. DATE OF 1ST SUBMISSION	14. DISTRIBUTION AND ADDRESSEES (Addressee—Regular Copies/Repro Copies)	
4. AUTHORITY (Data Item Number)		5. CONTRACT REFERENCE	7. DD250 REQ	8. APP CODE (A)	9. INPUT TO IAC (X)	11. AS OF DATE	13. DATE OF SUBSEQUENT SUBM/EVENT ID		
1. A005	2. Abstract of New Technology 3.		6. AFAL/RSP			10. AS REQD	12. AS REQD	14. See Block 3 of DID	ACO 2/0
4. DI-A-3028A		5.	7. LT	8. N	9.	11.	13.		
16. REMARKS									15. TOTAL 2/0
1.	2. 3.		6.			10.	12.	14.	
4.		5.	7.	8.	9.	11.	13.		
16. REMARKS									15. TOTAL
1.	2. 3.		6.			10.	12.	14.	
4.		5.	7.	8.	9.	11.	13.		
16. REMARKS									15. TOTAL
1.	2. 3.		6.			10.	12.	14.	
4.		5.	7.	8.	9.	11.	13.		
16. REMARKS									15. TOTAL

PREPARED BY	DATE	APPROVED BY	DATE
STANLEY L. ROSTOCKI AFAL/RSP	74 Aug 07	RICHARD JENNEWINE, ACTG 665A PROG MGR	74SEP27

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1.4 SUMMARY AND CONCLUSIONS

The transport units #1 and #2 have been tested and evaluated to the requirements of the Statement of Work. Unit #1 performance at +50°C and -5°C was well within the required goals. The 70,000 feet altitude environment had very little effect on all the measured parameters of flutter, jitter, skew, tracking, Signal to Noise (S/N), Bit Error Rate (BER), BER profile, flutter profile, and jitter profile. Performance at component resonant frequencies at the 0.5g. test level were unsatisfactory for both recorders.

The analysis of unit #2 concludes that the optimum HDMR tape transport design is the co-planer design that we had alternately considered for the AF application but had by-passed in favor of the coax design because of its more favorable "foot-print". It is now our opinion that the coax design is better suited for unmanned spacecraft applications. The co-planer design has already been chosen for NASA space shuttle applications and because of the vibration tests just completed, is now chosen for the AF applications also. This consistency of design for both AF and NASA will result in eventual lower costs for both users. The first unit of this latter design is now operational. Vibrational testing for NASA is not a requirement, so shaking this unit may or may not happen in the near future unless it is done under a new program (AF or otherwise).

Flutter, skew, jitter, head-to-tape interface, head life and tape life are all now considered of adequate capabilities for the MIL-E-5400 applications.

The nominal HDMR flight recorder requirements suggest further development in storage capacity which means longer tape (larger diameter reels) and/or higher packing density, and wider tape and LSI electronics to keep the recorder size down. A photograph of the co-planer tape transport is shown with 14 inch reels in Figure 1-1. This unit will presently accommodate 16 inch reels and by moving the reels, can accommodate reels up to 30 inch diameter.

An airborne HDMR tape transport which must operate under vibration conditions is quite feasible with certain design changes as shown by tests tests. All tracking, skew and BER problem areas are related to resonances of transport elements which can either be eliminated or adequately stiffened in a final design. The other parameters are in compliance with the requirements.

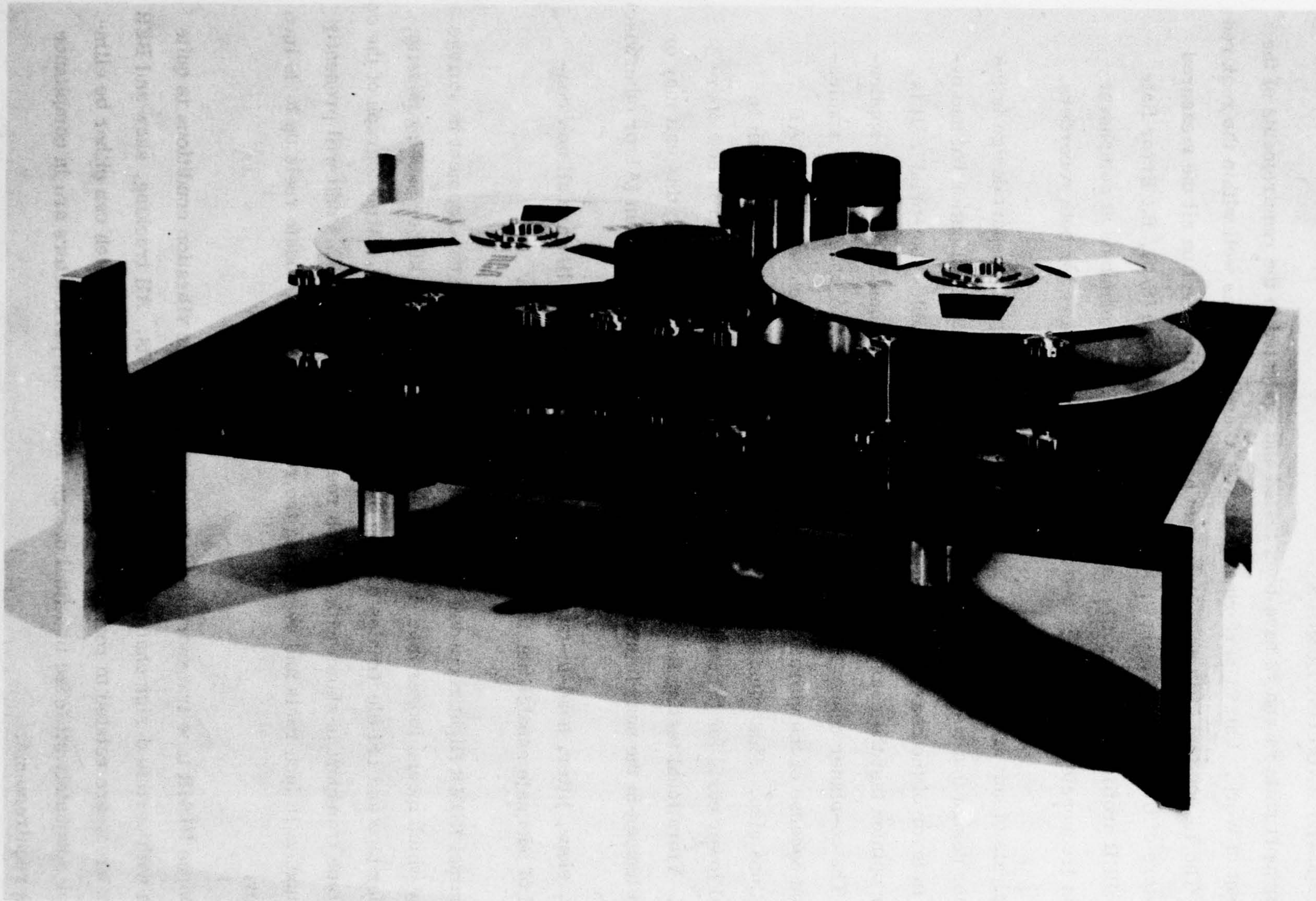


Figure 1-1. HDMR Coplaner Tape Transport

2.0 TAPE UNIT TESTING

2.1 PURPOSE OF TAPE TRANSPORT UNIT TESTS

Breadboard tape transport units were tested under reduced environmental conditions beginning at MIL-E-5400.

The results were utilized to determine performance capabilities, operating characteristics, temperature responses, and to make correlations between these and the vibration response of the transport elements. The transport performance goals include the following:

BER/Channel	10^{-5}	(redundant head or EDAC)
Flutter (cumulative percent)	1.0	
Jitter (μs p-p)	250	
Skew (μ inch/inch)	400	
Tracking (mils)	3	
Tape/Head Contact (μ inch)	<10	
Tape Tension (lb)	1.6 to 2.4	

Evaluation of this data determined the area and nature of required modification.

2.2 DESCRIPTION OF ITEMS TESTED

2.2.1 TRANSPORT UNIT NO. 1

(1) TRANSPORT

This unit was a breadboard test set-up for an IR&D program requiring high density multitrack digital recording. Use was made of component designs from a transport utilized by NASA to provide high density rotary head recording while in satellite orbit. The NASA unit was designed to operate with no vibration at temperatures between 70°C and 30°C at altitudes of 100 to 150 miles. It was required to withstand a vehicle launch vibration ranging from 4 to 9 G's in the nonoperating condition. Figures 2-1 and 2-2 show front and rear views while Table 2-1 shows functional capability.

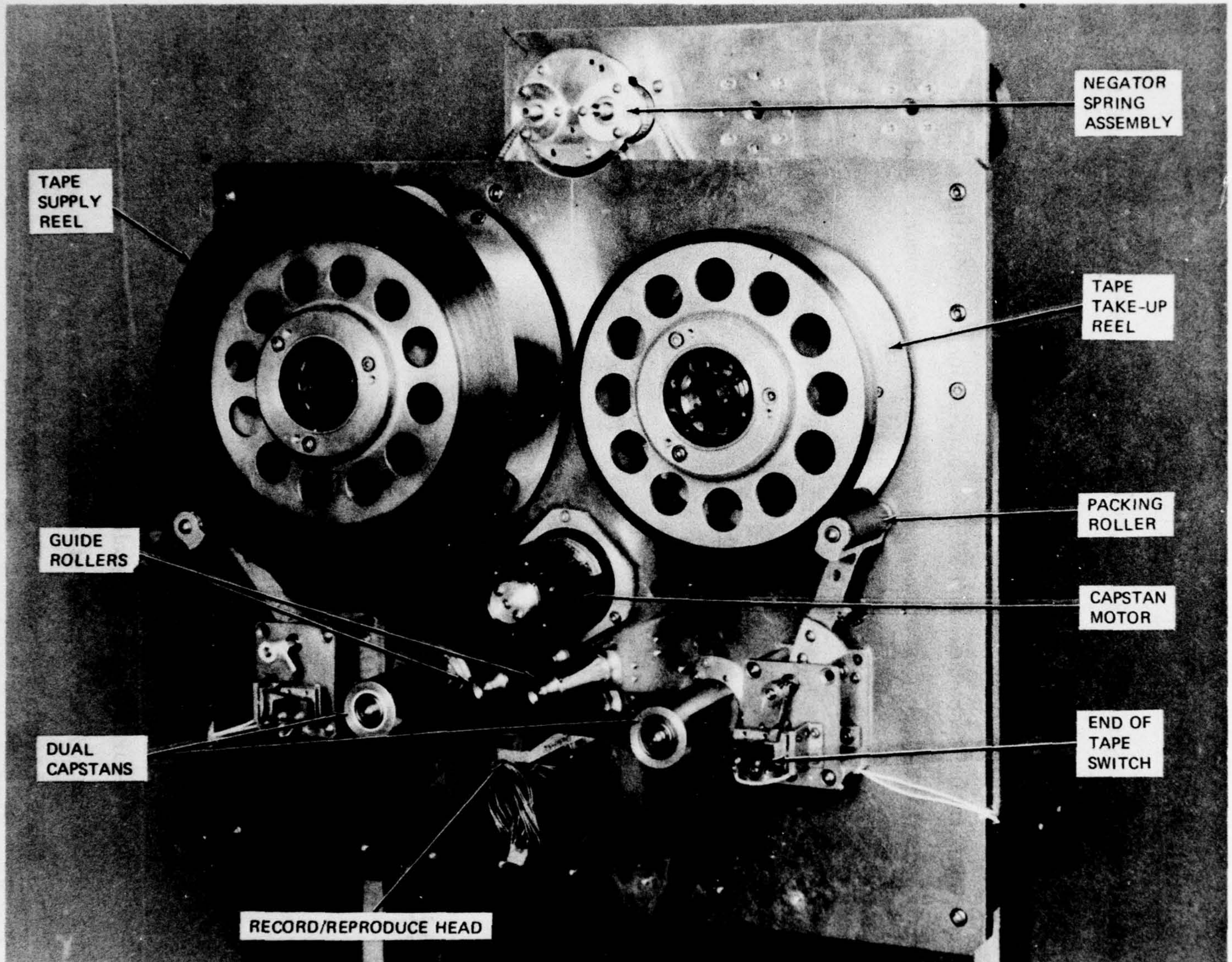


Figure 2-1. Tape Transport Unit No. 1

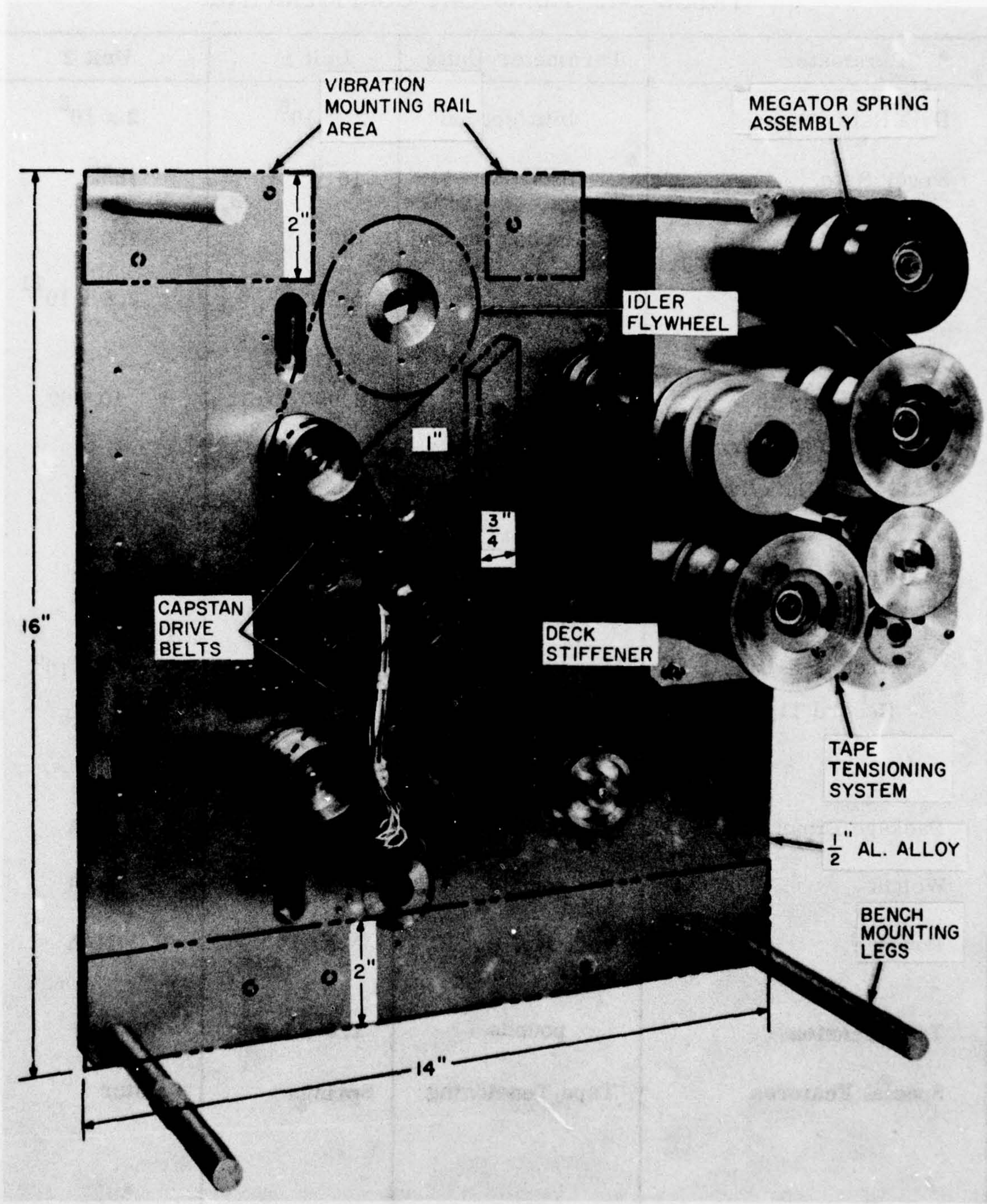


Figure 2-2. Tape Transport Unit No. 1 - Rear View

TABLE 2-1. TRANSPORT CONFIGURATION

Parameter	Parameter Units	Unit 1	Unit 2
Data Rate /Channel	bits/second	2×10^6	2×10^5
Error Rate	bits	10^{-6}	10^{-6}
Tape Speed	inches/second	100	100
Capacity	bits	5.7×10^{10}	2.8×10^{11}
Tape Width	inch	2	2
Tape Length	feet	2,000	10,000
Reel Diameter	inches	Non-Std	16
No. of Data Tracks		142	142
Track Width	inch	0.006	0.006
Tracks/Inch		71	71
Data Density/Track	bits/inch	20K	20K
Area Density	bits/inch^2	1.4×10^6	1.4×10^6
Record Time	minutes	4	20
Package Dimensions	inches	N/A	N/A
Weight	pounds	N/A	N/A
Power	Vac, Hz, ϕ, watts	N/A	N/A
Tape Tension	pounds	1.0 - 1.5	2.0
Special Features	Tape Tensioning	Springs	Motor

Replacement of the rotary head by a 142 trackhead, and modification of the layout to accommodate it, achieved the high density multitrack digital recording desired.

The configuration was a conventional longitudinal recording in-plane reel-to-reel machine with flangeless reels. The tape from the supply reel passed over a guide roller 180° around a driving capstan, across the head, then symmetrically over another capstan and guide roller to the take-up reel. The guide rollers and capstan were the cylindrical non-contoured type. The two tape drive capstans were belt driven in parallel by a single motor. Flanged, springloaded diameter sensing rollers guided the tape at the reels and contributed to tight winding on the take-up reel. Tape tension was maintained by two sets of dual negator spring motors (nominally constant torque drive) working through a differential gear system which drove the supply and take-up reels.

(2) CONTOURED GUIDE ROLLERS

Two types of experimental guide rollers with contoured roller surfaces were installed in transport unit 1 for determining their effect on tracking at both room temperature and 35°C. This configuration is portrayed in Figure 2-3, types A and B.

(3) MAGNETIC TAPE

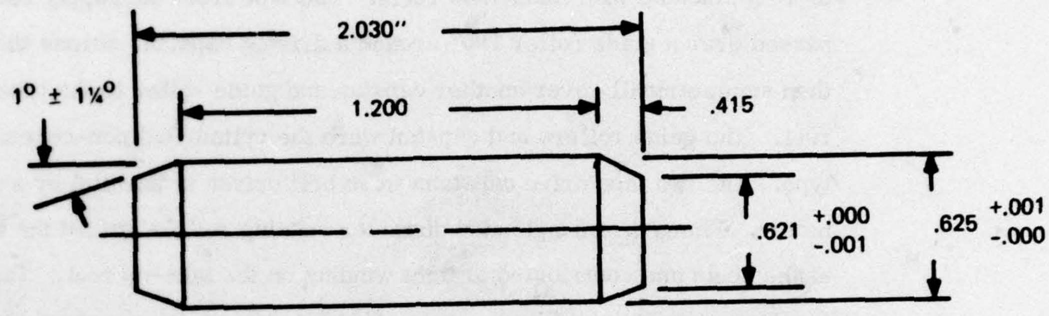
The tests on unit 1 were performed with new (virgin) 3M MTA 20478 tape, sample 6B. (This tape has subsequently been made into a commercial product, 3M 971).

2.2.2 TRANSPORT UNIT NO. 2

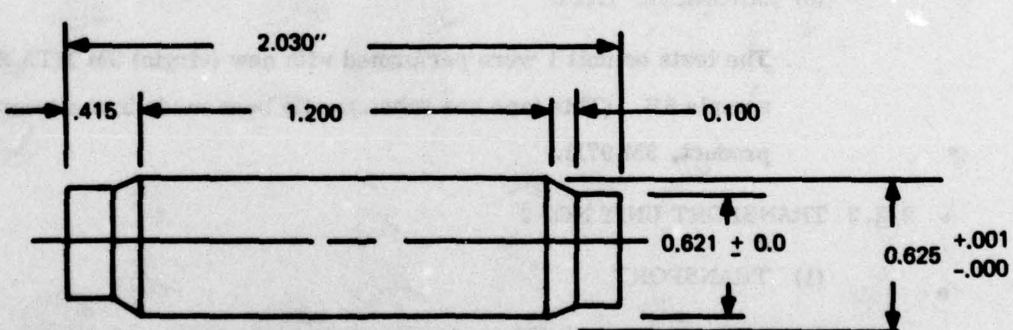
(1) TRANSPORT

The unit was a breadboard test set-up constructed with inhouse IR&D funds as a further development in achieving the goals for the AF UPD-X airborne high density tape transport program. Figures 2-4 and 2-5 show front and rear views while functional capability is given in Table 2-1.

The drive and guide elements and the deck plate were designed with high rigidity to meet the vibration requirements of MIL-E-5400. Large flanged



CONTOUR ROLLER A



CONTOUR ROLLER B

Figure 2-3. Experimental Contoured Guide Capstan Rollers

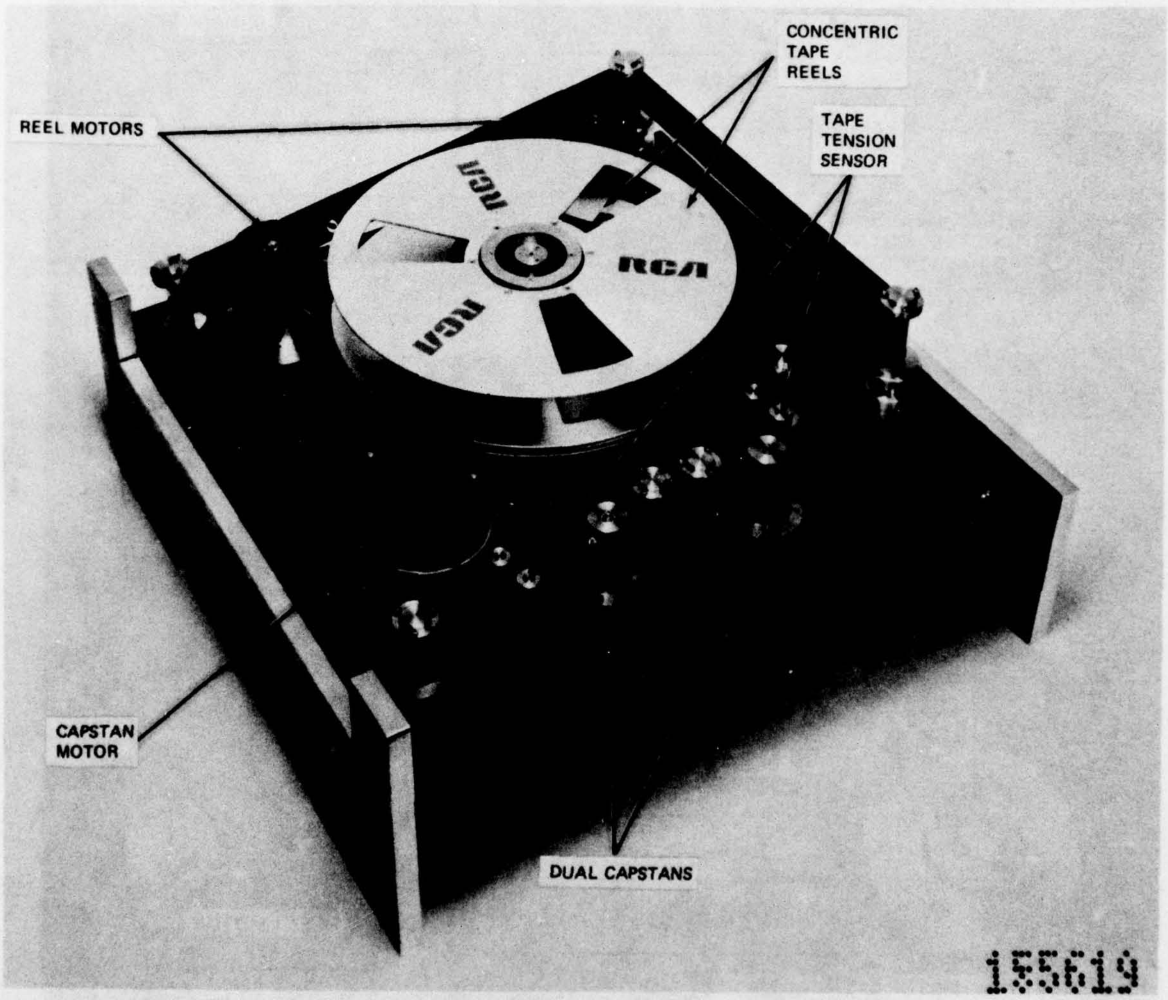


Figure 2-4. Tape Transport Unit No. 2 - Face View

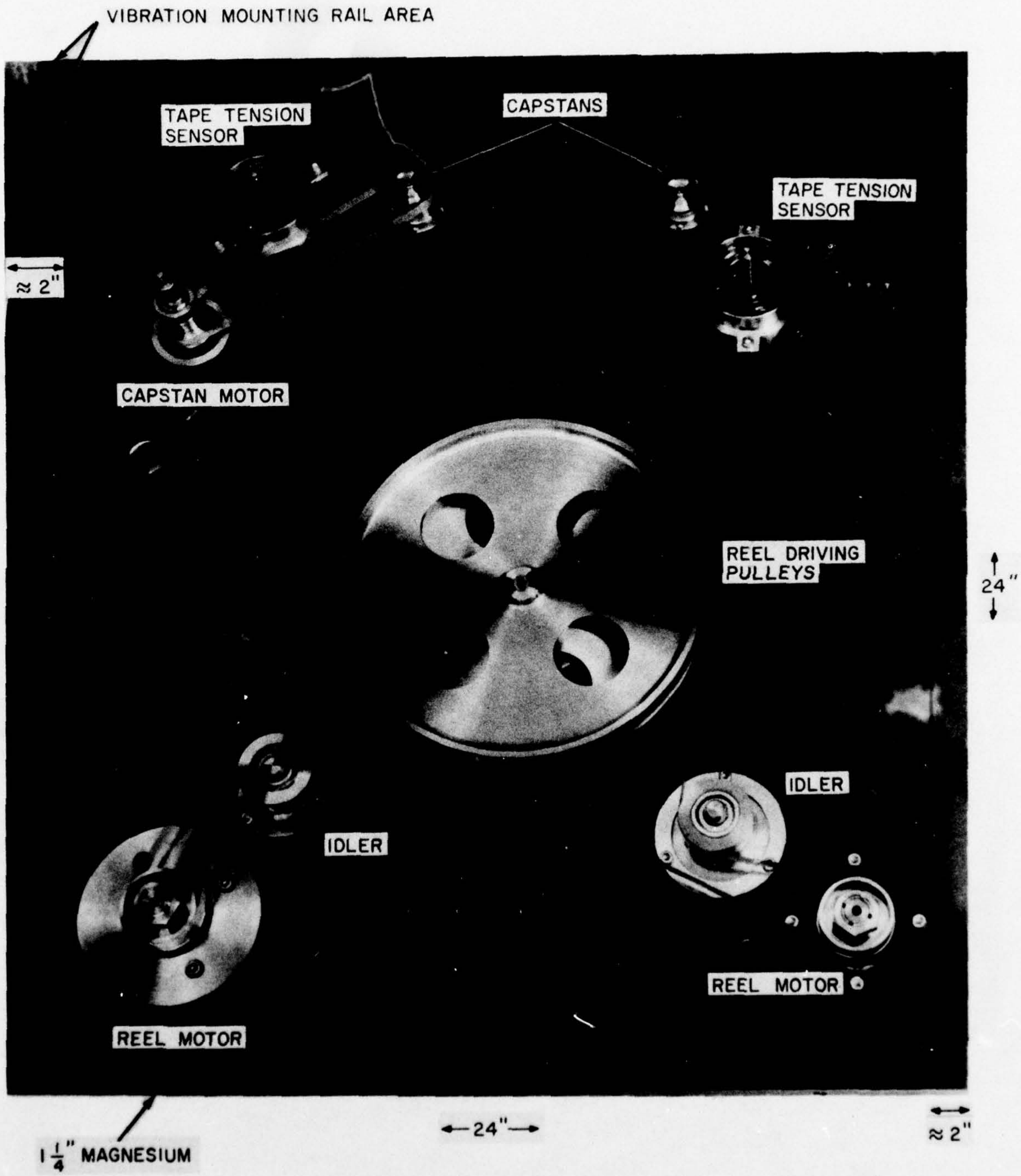


Figure 2-5. Tape Transport Unit No. 2 - Rear View

tape reels were needed to provide tape capacity with a capability of changing reels as required. In addition, a servomotor controlled drive system was added for improved tension and tape speed control.

A configuration with coaxially mounted reels was selected for minimum system volume and footprint dimensions. The tape path level change from supply to take-up reel was accomplished by a series of vertical and angled guide rollers with a twist in two legs of the tapepath. The two tape drive capstans were belt driven in series by a single motor. Guide rollers and capstans were of the cylindrical (noncontoured) type. Tape tension was dynamically controlled by separate servomotors driving the take-up and supply reels with corresponding tape tension sensors.

(2) MAGNETIC TAPE

The tests on unit 2 were performed with 3M 971 tape. See tape specification on 2-10 (This tape was previously designated 3M MTA 20478, Experimental Sample).

2.3 TEST PROCEDURES

2.3.1 SUMMARY OF TESTS

Measurements of various operating parameters of the transport units were made during one axis of vibration under ambient conditions. Acceleration measurements on various transport elements were taken for all three axes of vibration. The vibration level was .5 g maximum from 5 to 2000 Hz. In addition, tracking measurements were made at 35°C (and room ambient) on unit 1 with both the straight and two types of contoured rollers. Table 2-2 lists the tests conducted and measurements taken.

2.3.2 PARAMETER MEASUREMENT PROCEDURES

(1) BIT ERROR RATE (BER)

(a) UNIT 1 RECORDED SIGNALS

Prior to testing the tape was preconditioned by running it for 2814 passes in each direction against the head and using 3M tape cleaning

MAY 1971

WIDEBAND TEXTURED BACK

OCT 26 1971

Scotch® BRAND 971

HIGH ENERGY INSTRUMENTATION TAPE

TECHNICAL DATA

Physical Properties	Units	Test Notes	971
Color			
Substrate	—	—	Dull Black
Oxide Coating	—	—	Shiny Brown
Substrate	—	—	Textured Polyester
Thickness			
Substrate	Mils	1	1.00
Oxide Coating	Mils	1	0.11
Total	Mils	1	1.11
Width Tolerance	Inches	2	+0.000/−0.004
Static Tensile		3	
Yield Strength	lbs./½″ width	4	6.4
Breaking Strength	lbs./½″ width	5	12.4
Elongation at Break	Percent	5	95
Residual Elongation	Percent	6	0.5
Shock Tensile Strength	ft.-lbs.	7	>1.16
Coating Wearability (100 Passes)	Generated Dropouts	8	<1/100′/Track
Surface Resistance			
Substrate	Megohms/sq. area	9	<5
Layer-to-Layer Adhesion			
150°F at 85% R.H.	—	10	Surpasses Requirements

Intrinsic Magnetic Properties			
Coercivity (H_{ci})	Oersteds	11	530
Retentivity (B_{rs})	Gauss	11	1500
Erasing Field Required	Oersteds	12	1000

Electro-Magnetic Performance*			
Signal-to-Noise Capability			
Wideband	Decibels	13	28
Slot			
10 mil wavelength	Decibels	14	58
1 mil wavelength	Decibels	14	72
1/2 mil wavelength	Decibels	14	73
1/4 mil wavelength	Decibels	14	71
1/8 mil wavelength	Decibels	14	66
1/10 mil wavelength	Decibels	14	64
1/12 mil wavelength	Decibels	14	62
1/16 mil wavelength	Decibels	14	55
1/24 mil wavelength	Decibels	14	50
Dropouts			
Per 100′ at 0.15 mil wavelength	—	15	<2

*As measured on a wideband recorder/reproducer.

TEST NOTES

1. Total thickness measurements are averages for ten layers of tape taken over a length of approximately two feet. ASTM D374-57T, Method A, is used to measure to 0.0001 inch. The average thickness per layer is calculated. Coating thickness figures are the difference between average per layer thicknesses measured before and after the coating in question is removed.

2. Width is measured on an optical device that has a magnification of at least 5.

3. Static tensile tests are performed at a constant rate of jaw separation of 2 ipm from an initial separation of four inches as specified in EIA Standard RS-362 (Tensile Properties).

4. Yield strength is defined as that force which produces significant permanent elongation of the sample (otherwise termed the 3% elongation point). It is measured during static tensile testing. (See NOTE 3).

5. Breaking strength is equivalent to ultimate strength for the magnetic tape backing described and is self-explanatory. Both the force to cause rupture and the sample's elongation at rupture are measured during static tensile testing. (See NOTE 3.)

6. Residual elongation is that elongation, expressed as a percentage of the original length, which remains after a stressed sample is permitted to recover at zero stress. Test method is that of Federal Specification WT-001553 for "Elongation Under Stress" in which initial sample length is 20 inches, stressing and recovery times are 3 hours each, and applied load is 5 lbs. for ½ inch wide tapes.

7. Shock tensile strength is a measure of the kinetic energy absorbed by ½ inch wide tape before rupture occurs. Test method is that of NASA Specification X-534-67-195.

8. Coating wearability is a measure of a tape's ability to resist the normal degrading effects of abrasive wear during actual use. It is measured and expressed in terms of the number of dropouts (See NOTE 15) per 100 feet per track generated during 100 forward passes of 1000 feet of tape on a typical wideband recorder/reproducer.

9. Substrate surface resistance indicates the tendency of a tape to hold a static charge established through normal conditions of use. Tapes with resistivities above 200 megohms per square are susceptible to charge accumulation and associated problems, especially at high speeds and low humidities. Test Method is that of FED-STD-406, Method 4041, Figure b. Conditions of test are 70° ± 5°F, and 30% R.H. or less.

10. Temperatures and humidities listed represent conditions under which there will be no coating transfer when using the test method of EIA Standard RS-339.

11. Intrinsic coercivity is that field intensity required to reduce induction from saturation to zero. Retentivity is that induction per unit cross section area retained by the tape when the field intensity is reduced from 3000 oersteds to zero. These properties are measured using a 60 Hz dynamic B-H vs. H. hysteresis loop tracer calibrated in terms of volt-ampere standards traceable to those maintained by the National Bureau of Standards.

12. The required erasing field is that peak value of a 60 Hz alternating field which will cause at least a 60 db reduction in level of a 1 mil wavelength saturated signal pre-recorded on the tape.

13. The wideband (unfiltered) signal to noise is the ratio of a typical, wide bandwidth, direct recording system's output to the wide bandwidth noise level. The measurement is made with an average responding voltmeter calibrated to read R.M.S. volts. The record level of the system is calibrated for 1 percent 3rd harmonic distortion at a frequency of 1/10 maximum high band edge for this measurement.

14. The slot signal-to-noise ratio is defined in the same manner as wideband signal-to-noise (see NOTE 13), except that the input to the meter is filtered to a 1 kHz bandwidth, centered about the wavelength specified. A Hewlett-Packard model 310A wave analyzer or equivalent may be used. 1/24 mil wavelength is measured on a recorder equipped with heads and electronics modified to resolve the signal, i.e., more efficient heads and 60 ips equalizers modified to pass frequencies up to 1.5 MHz.

15. Dropouts are instantaneous non-uniformities of a recorded signal caused by a head to oxide surface separation that reduces the reproduce signal level by 50% or more for a time duration of 20 microseconds or longer. They are measured at a 0.15 mil wavelength (800 kHz/120 ips) with a head having a 50 mil wide track which conforms to IRIG Standard 106-69.

The data has been compiled from our own laboratories. The data is typical, determined by experience and can be used for comparative purposes.

HIGH ENERGY

Magnetic Products Division 3M COMPANY

M-IL 151(57.5)R2

TABLE 2-2. ENVIRONMENTAL TESTS AND MEASUREMENTS

Parameter Measured	Test Condition								
	Ambient	Vibrate (Rail Control Unless Noted)							35°C
		X Axis Sweep		Fixed f.	Z Axis Sweep		Y Axis Sweep		
		Non Op.	Op.	Op.	Non Op.	Op.	Non Op.	Op.	
Transport Unit 1									
BER									
1-Head	X								
2-Heads	X		X	X					
Flutter	X			X					
Jitter	X								
Skew	X			X					
Tracking									
Straight Roller	X								X
Contour A	X								X
Contour B	X								X
Acceleration		X			X		X		
Transport Unit 2									
BER									
1-Head	X			X					
Flutter	X			X					
Jitter	X			X					
Skew	X			X					
Tracking Straight Rollers	X		X	X		X Deck Control		X	
Acceleration		X X Deck Control			X Deck Control		X		

tissue to remove debris. A pseudorandom series of 10^6 word length of 2 Mb/s data rate was recorded for 2000 feet of tape and the tape was rewound to the supply reel. The tape was permitted to come up to speed (lock in) and the BER measurements were taken continuously from beginning to end. For the check of BER versus single and dual head recording and repeatability at ambient conditions, see paragraph entitled "additional procedures." The remaining test of BER were made using a single two track channel redundantly recorded. Data was recorded at ambient conditions and then played back under a vibration or temperature environment for evaluation.

(b) UNIT 2 RECORDED SIGNALS

The psuedorandom series of 511 bits, word length of 2 Mb/s data rate, was recorded for ten thousand feet of tape with no tape burnishing and the tape was rewound on the supply reel. The tape was permitted to come up to speed and BER measurements were made continuously from beginning to end. A single head and tape track were used. The data was recorded at ambient conditions and played back under the vibration environment for evaluation.

(c) BER VERSUS SINGLE AND DUAL HEAD RECORDING AND VERSUS REPEATABILITY

This nonvibrating test was performed using transport unit 1. Track 10 and 15 recorded identical data with heads connected in parallel. The tapes were rewound and played back with the heads wired paralleled and then with each head read individually. For each head playback condition, the tape was rewound and a second playback was made. Error samples of ten second intervals were made for the 160 seconds of data recorded for each playback made. BER was calculated as follows:

$$BER = \frac{e}{t \times DR}$$

BER = Bit Error Rate (errors/bit)

e = total number of errors in time (t)

t = total time in seconds

DR = Data Rate (bits/second)

(d) BER TEST SET UP

A block diagram of the digital data record/playback system is shown in Figure 2-6 and 2-6A. The decoder program is a multichannel decoder with selfcontained PLO (phase lock oscillator). The system was designed to detect all bit error. Bit error occurs when the playback signal is reduced to 10 dB below full output. Data obtained with this unit was consistent from run to run (repeatable). Figure 2-7 illustrates this test set up.

(e) UNIT 1 BER VIBRATION TESTS

BER checks taken during vibration were performed on unit 1 with heads 10 and 15 in parallel. Error print out samples of one second duration taken. The test sequence was:

Test Performed	Vibration Condition
Data recorded on tape	None
BER Check	None
Transport nonoperating Acceleration Recorded	5 to 2000 Hz Sweep
BER Check	None
BER Check - Continuous	5 to 850 Hz Sweep
BER Check	None
BER Check Continuous	850 to 2000 Hz Sweep
BER Check	Fixed resonant frequencies

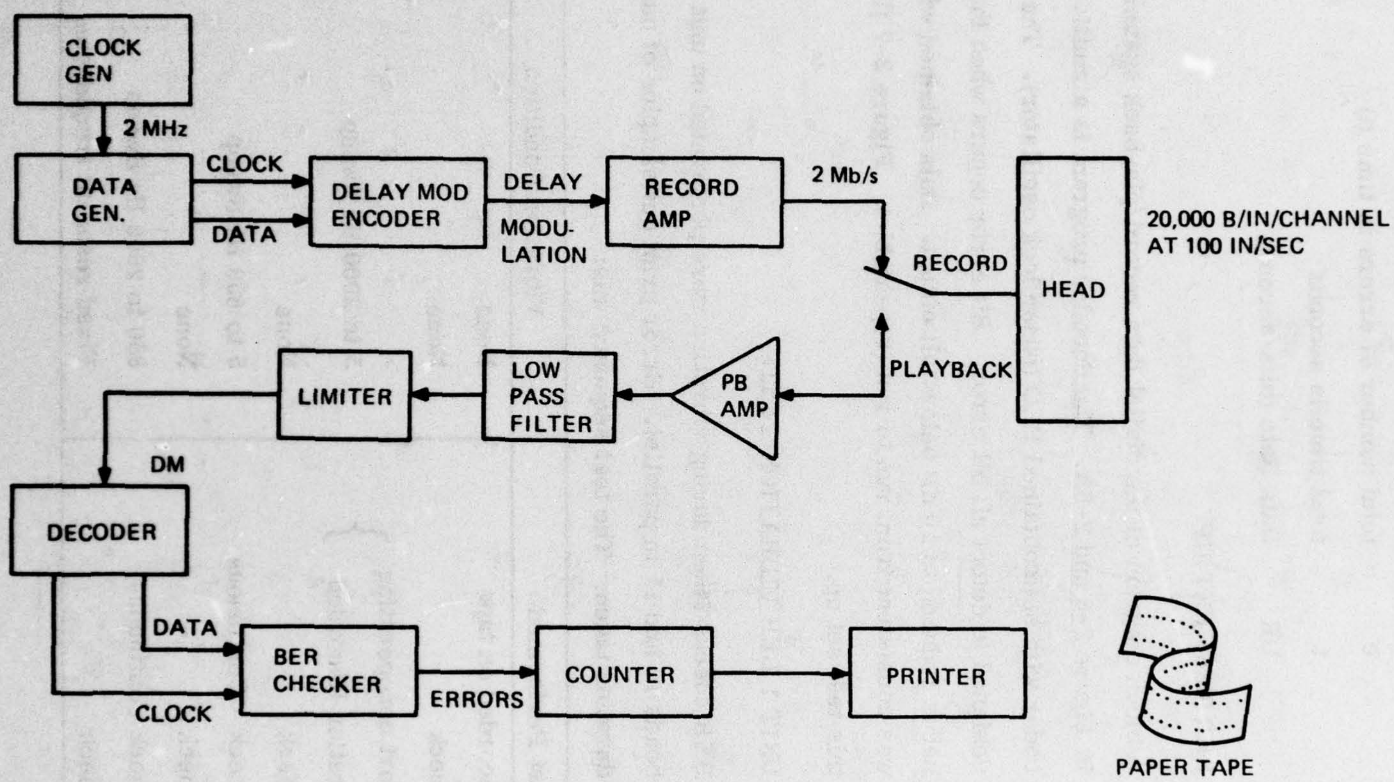


Figure 2-6. Recorder Channel Electronics and BER Test Instrumentation

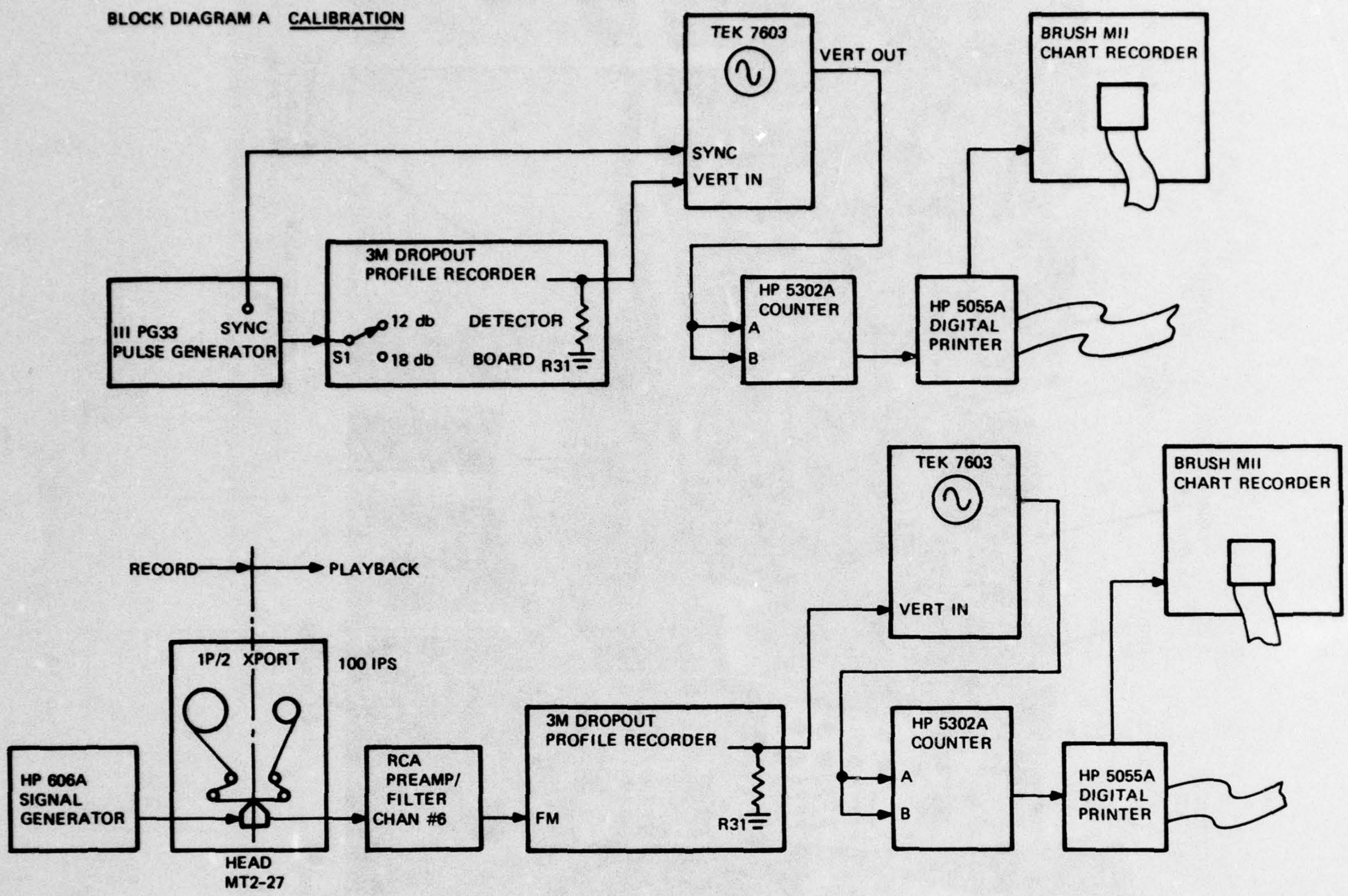


Figure 2-6A. Block Diagram B Measurement

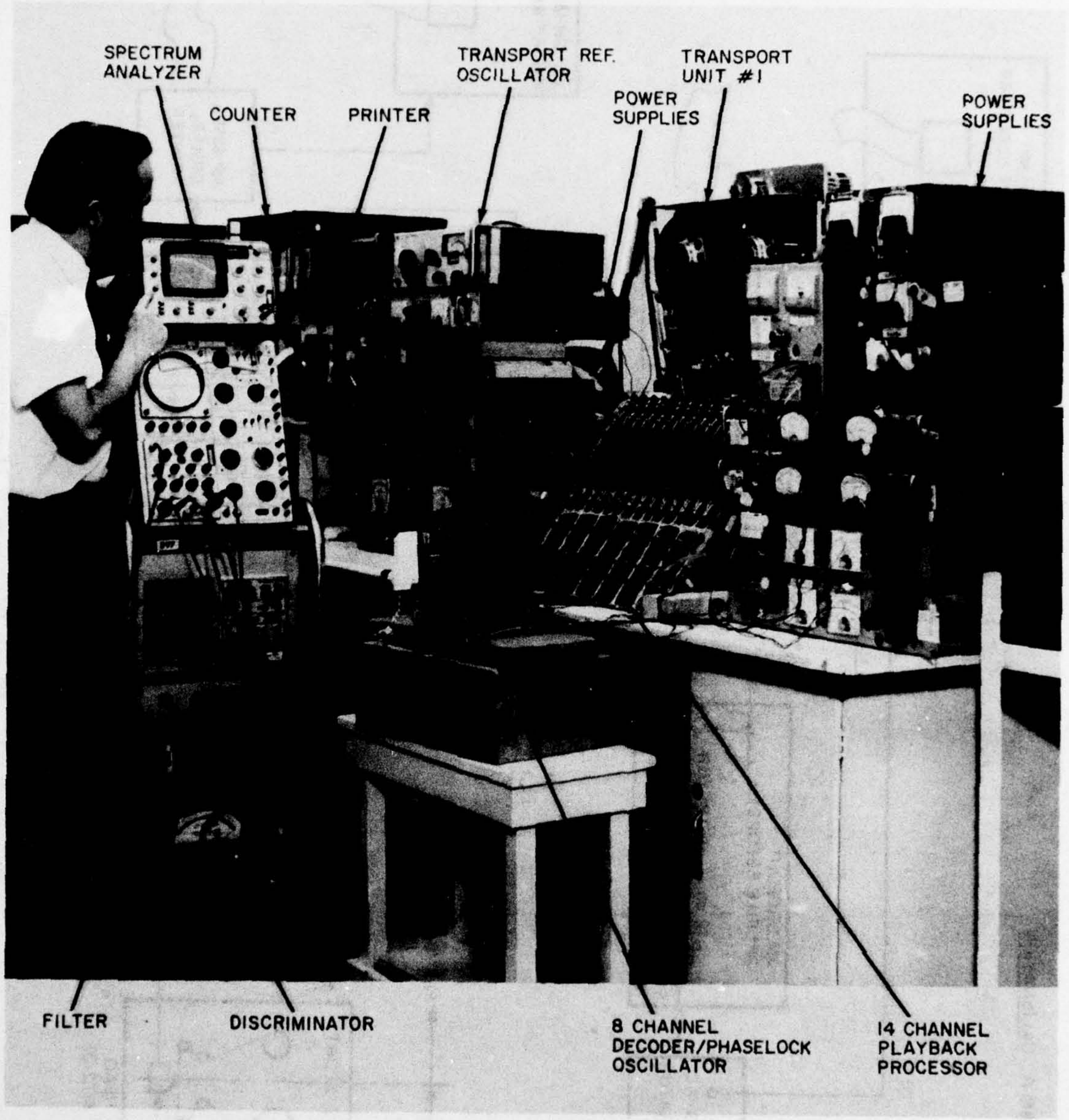


Figure 2-7. Laboratory Test Set-Up for Record and Playback

(f) UNIT 2 BER VIBRATION TESTS

BER checks on unit 2 were performed with only number 4 head. Readings were taken before and during vibration in the X axis. A 5-2000 Hz sweep vibration was made to determine component acceleration resonant frequencies with the transport not operating. A second sweep was made with the transport operating primarily to obtain other electrical data. BER data recorded during this run was not closely tied to frequency and was only retained for possible reference. The BER was then taken at each of the resonant frequencies.

(2) FLUTTER

A single frequency (100 kHz for unit 1 and 25 kHz for unit 2) was recorded nonvibrating and played back in the same direction for evaluation. The block diagram for flutter measurements of units 1 and 2 are given in Figure 2-8 and 2-8A for other measurements. The tape was recorded and played back at 100 inches/second. The percent flutter and flutter frequency were tabulated nonvibrating. The transport was then vibrated in the X axis at fixed resonant frequencies of the acceleration X, Y plots and the flutter data recorded.

A set of nonvibrating measurements of discrete and cumulative flutter were taken at 80 inches/second during development of the transport. Some actual components from the transport were used in the subject unit 1 transport, therefore, this data is included for reference. Discrete measurements were read from the display of a 1/10 octave frequency analyzer, GR 1564A. Cumulative measurements were read from an HP 3400A RMS voltmeter through a Krohn-Hite 330M bandpass filter set at each upperpass band frequency.

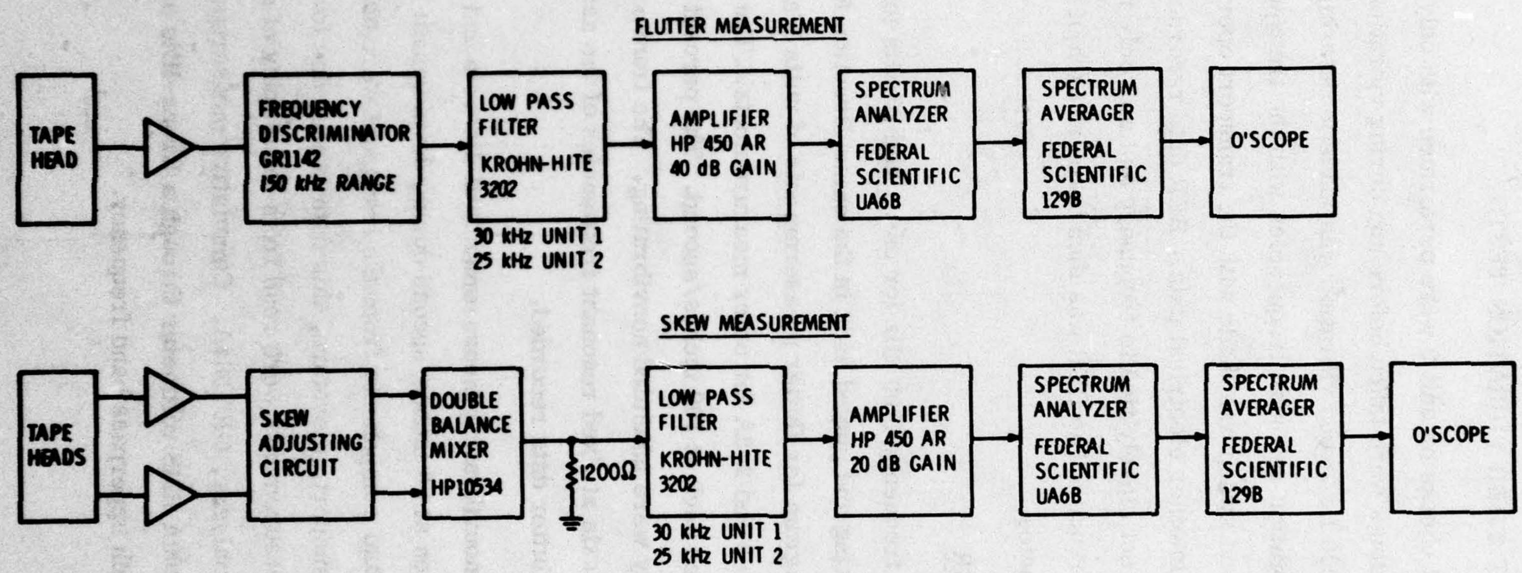


Figure 2-8. Flutter and Skew Measurement Block Diagram

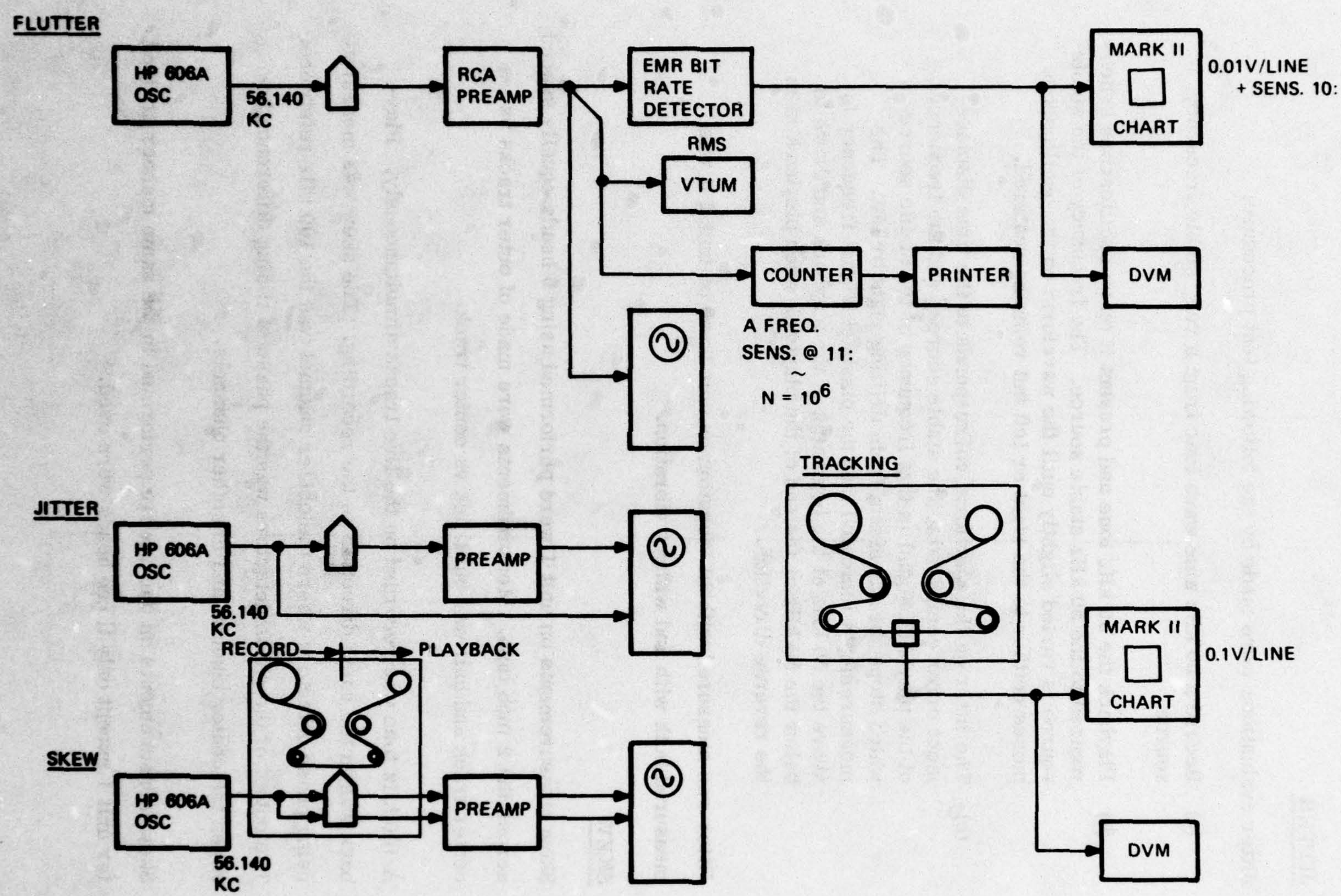


Figure 2-8A. Test Set-Up

(3) JITTER

Jitter evaluations were made by the following test procedure:

(a) Record a 50 kHz sine wave tone from a very stable frequency source.

(b) Playback the 50 kHz tone and present it on an oscilloscope synchronized to the 50 kHz stable source. The frequency of the stable source is varied slightly until the waveform on the oscilloscope moves neither to the right or left but remains centered.

(c) The jitter on the waveform corresponds to the time displacement error compared to the stable source, and the frequency of the playback signal is that frequency of the stable source which stops the waveform from drifting right or left. The measurements indicated that the playback signal frequency is above the 50 kHz at the beginning of the playback and drifts to below the 50 kHz at the end of the playback when playback is in the reverse direction.

Jitter was measured without vibration on unit 1 and on unit 2 it was measured both with and without vibration.

(4) SKEW

Skew measurements on unit 1 were performed using 5 heads equally spaced across the 2 inch tape. Measurements were made of outer tracks vs center track and half way out track vs center track.

A 100 kHz tone was recorded on the five tracks simultaneously. Playback was in the same direction as the recording. The skew was measured using phase detectors where the center channel was the 100 kHz reference. The output of the phase detectors was the phase of timing difference between the center channel and the other channels.

Skew measurements on unit 2 were performed in the same manner utilized for unit 1 except only three heads were used.

(5) TAPE TRACKING

(a) UNIT 1

Because of the importance of having optimum playback of narrow tracks the tracking alignment during playback was assessed by a unique and sensitive experimental technique. An experimental fixture was made for this purpose, shown in Figure 2-9. Conventional audio heads were mounted in special head blocks to adapt the heads for use with two inch wide tape. A single record head, with a 1/4 inch wide track was mounted in a fixed block, so as to lie in the tape center line. Two playback heads with .060 inch wide tracks were in a second block with their track centers 1/4 inch apart. The playback block was mounted in a precision slide, and was equipped with a micrometer head, to allow accurate lateral positioning relative to the tape center line. When the playback block was centered each playback head center was over an edge of the record track. For this nominal condition each playback head would "see" a recorded signal equivalent to that of a .030 inch wide track. If either the head block or tape were moved laterally, one head would "see" a wider track and the other head would see a narrower track. The two playback amplifiers were adjusted for equal voltage output when the block was centered during simultaneous record-and-playback. The two playback signals were fed into a simple comparator circuit which developed a DC signal in proportion to the differential level of the two head signals. This DC output voltage versus mils lateral displacement was calibrated during simultaneous record-and-playback by adjusting the micrometer attachment. This tracking signal proved to be quite linear with and sensitive to lateral motion.

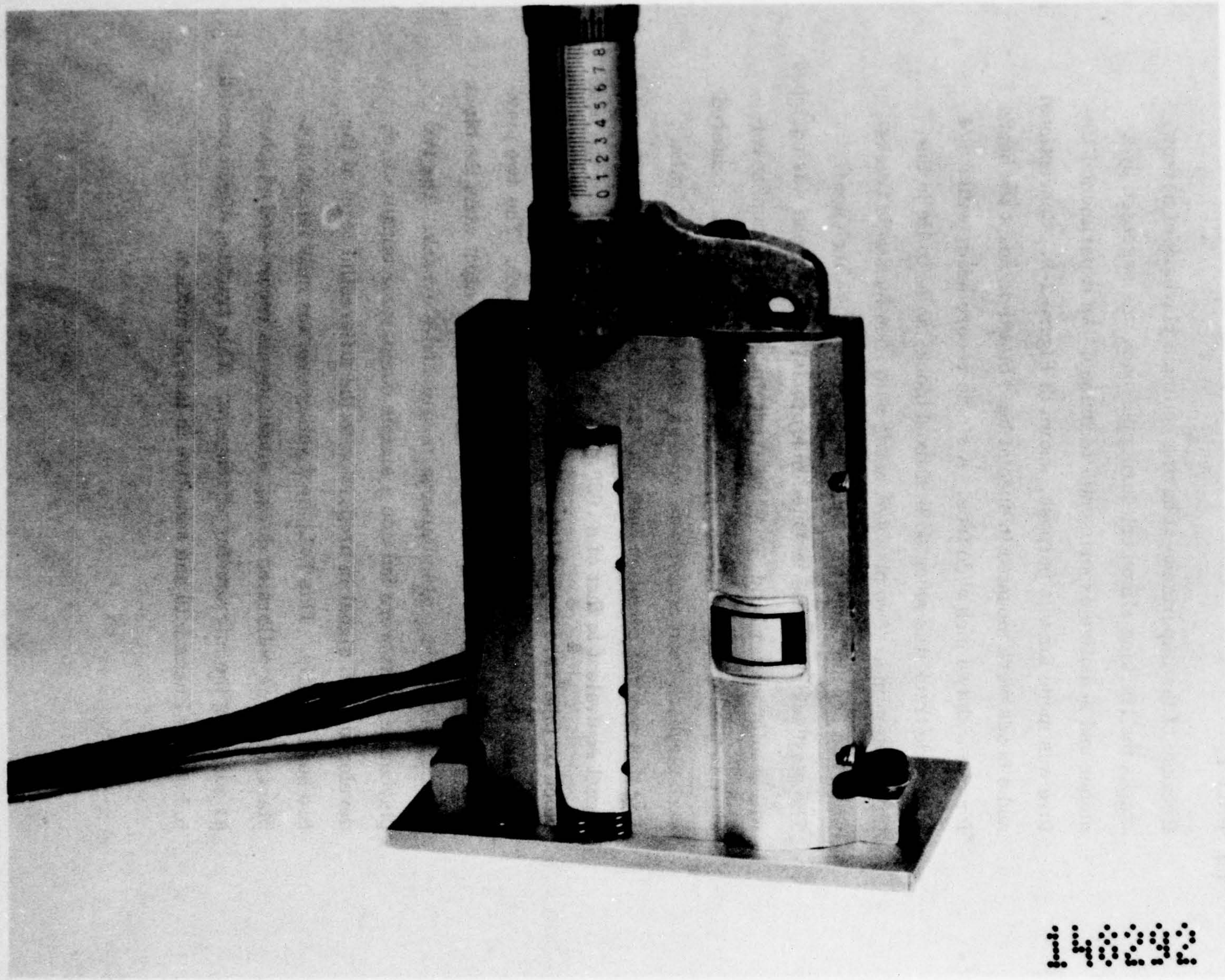


Figure 2-9. Tape Tracking Sensing Fixture

The testing phase was done with the playback head block centered. A recording was made at room temperature, rewound, and played back. The error signal of the tracking fixture was recorded on a Visicorder and in general had the appearance of an AC carrier about 1000 Hz which changed its center line location (i.e., average DC value) gradually.

All unit 1 tracking tests were performed nonvibrating. Tracking test runs were made with each of the three types of guide rollers at room temperature and also at 35°C. For the high temperature tests, the transport unit was stabilized at 35°C in an environmental temperature chamber and then operated. Several full length play backs were made at each condition.

(b) UNIT 2

Tracking measurements on unit 2 were made with a LED photocell edge tracking sensor on the outer edge of the magnetic tape. This gave an edge tracking signature and a tape slitting signature for both nonvibrating and vibrating tests conditions; independent of magnetic head data.

Measurements of the tape edge position with respect to the precision head mounting base plate were made with an HEI 561A optical position sensor. The sensor was located next to the HDMR head between the dual capstans. Figure 2-10 depicts the sensor and mounting bracket assembly. This system is linear over an 8 mil range with a 70 kHz frequency response. The output signal was fed to a Brush Instruments chart recorder for a permanent record.

A nonvibrating tape track record was made while running through the entire length of tape. A record of the tracking sensor output was

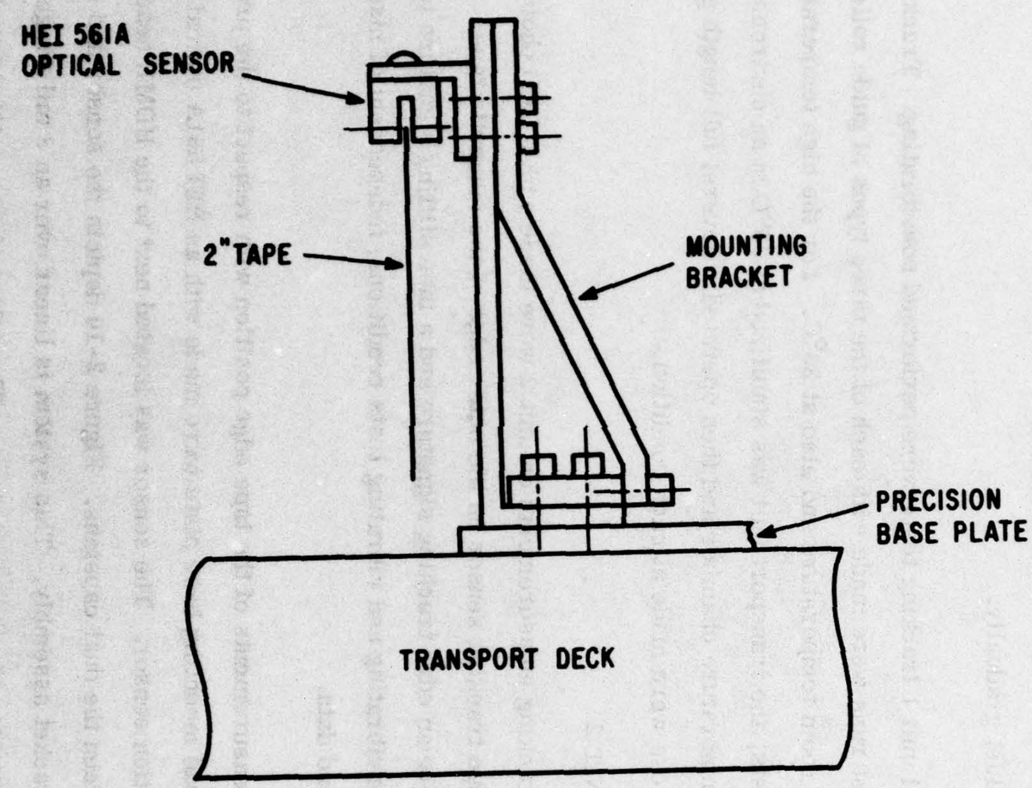


Figure 2-10. Tracking Sensor and Bracket Assembly for Unit No. 2 Tests

made with the tape stationary during the first vibration sweep. This was done to demonstrate that the sensor itself did not generate erroneous tracking signals when subjected to vibration. Finally, tracking data was recorded with vibration in each axis. While recording the tracking data, the vibration input level was controlled from the following locations for each axis:

X axis - side rail

Y axis - side rail

Z axis - deck

(An additional X axis run was made for acceleration data only, with the input control at the deck accelerometer location.)

(6) TAPE TO HEAD CONTACT

Tape to head contact was visually evaluated by observing the change in the level of data signals used for measuring BER.

Vibration conditions for these tests were based on those at MIL-E-5400, paragraph 3.2.24.5.1.2b, Figure 2, curve II, "Sinusoidal Vibration Requirements for Equipment Designed for Installation In Jet Airplanes - Equipment Designed for Operation on Isolators with Isolators Removed." All vibration tests were made at an input level of .5 g. Data was taken during frequency sweeps and at selected fixed frequencies. The frequency sweep rate was logarithmic from 5 to 2000 Hz in 10 minutes. Vibration was performed in all three axes on both units, but only selected data was taken under the various conditions. Table 2-2 shows what data was taken in each axis and whether it was taken during a sweep or fixed frequency condition. The fixed frequencies were maximum

response frequencies selected from the acceleration data and tuned to maximize the response. Tables 2-3 and 2-4 show the test sequence, actual frequencies used, and type of data (transport parameter or acceleration) taken during each run.

TABLE 2-3. TEST SEQUENCE TRANSPORT UNIT 1

Run No.	Control Location	Vibration Axis	Vibration Frequency (Hz)	Transport Operating ?	Data Taken
1	Rail	X	5-2000	No	Acceleration
2	Rail	X	5-2000	Yes	Electrical*
3	Rail	X	358	Yes	Electrical*
			374	Yes	Electrical*
			591	Yes	Electrical*
			745	Yes	Electrical*
			1742	Yes	Electrical*
4	Rail	Z	5-2000	No	Acceleration
5	Rail	Y	5-2000	No	Acceleration

*Except Jitter and Tracking

The transport deck was mounted on two inch thick side rails bolted to a baseplate. For the horizontal axes, X and Z, this assembly was mounted on a slip plate, and for vertical axis Y, directly to the shaker. Except for certain tests, the input vibration was controlled from the deck on unit 2 for the Z axis tests and a special run for acceleration data in the X axis.

Acceleration data was taken in all three axes in the form of acceleration versus frequency plots. The transports were not running and the tape was distributed equally on the supply and take-up reels. In the case of unit 2 the reel motors were powered to maintain tape tension.

TABLE 2-4. TEST SEQUENCE UNIT 2

Run No.	Control Location	Vibration Axis	Vibration Frequency (Hz)	Transport Operating ?	Data Taken
1	Rail	X	5-2000	No	Acceleration
2	Rail	X	5-2000	Yes	Elec. & Track
3	Rail	X	230	Yes	Elec. & Track
			279	Yes	Elec. & Track
			355	Yes	Elec. & Track
			430	Yes	Elec. & Track
			686	Yes	Elec. & Track
			728	Yes	Elec. & Track
			861	Yes	Elec. & Track
			915	Yes	Elec. & Track
			1604	Yes	Elec. & Track
4	Deck	X	5-2000	No	Acceleration
5	Deck	Z	100-2000	No	Acceleration
6	Deck	Z	100-2000	Yes	Tracking
7	Rail	Y	100-2000	No	Acceleration
8	Rail	Y	100-2000	Yes	Tracking

A small accelerometer mounting block was cemented to each component of interest, permitting the accelerometer to be mounted in any of three mutually perpendicular axes. For each axis of vibration, the accelerometer was positioned on the block to read in the direction of vibration input.

2.4 UNIT 1 TEST RESULTS

2.4.1 BER MEASUREMENTS

BER VERSUS SINGLE AND DUAL HEADS IN PARALLEL AND VERSUS REPEATABILITY

Table 2.5 shows the maximum single track BER was 4.6×10^{-5} and 7.5×10^{-5} respectively for the two tracks tested individually. With two

Response accelerometers were mounted on Unit 1 transport as follows:

#1. On the end of the right-hand tape guide roller

#2. Near the end of the motor

#3. On the end face of the head

#4. On the deck near the head

#5. On the right-hand diameter sensing arm (roller follower arm)

#6. Near the end of the right-hand capstan housing

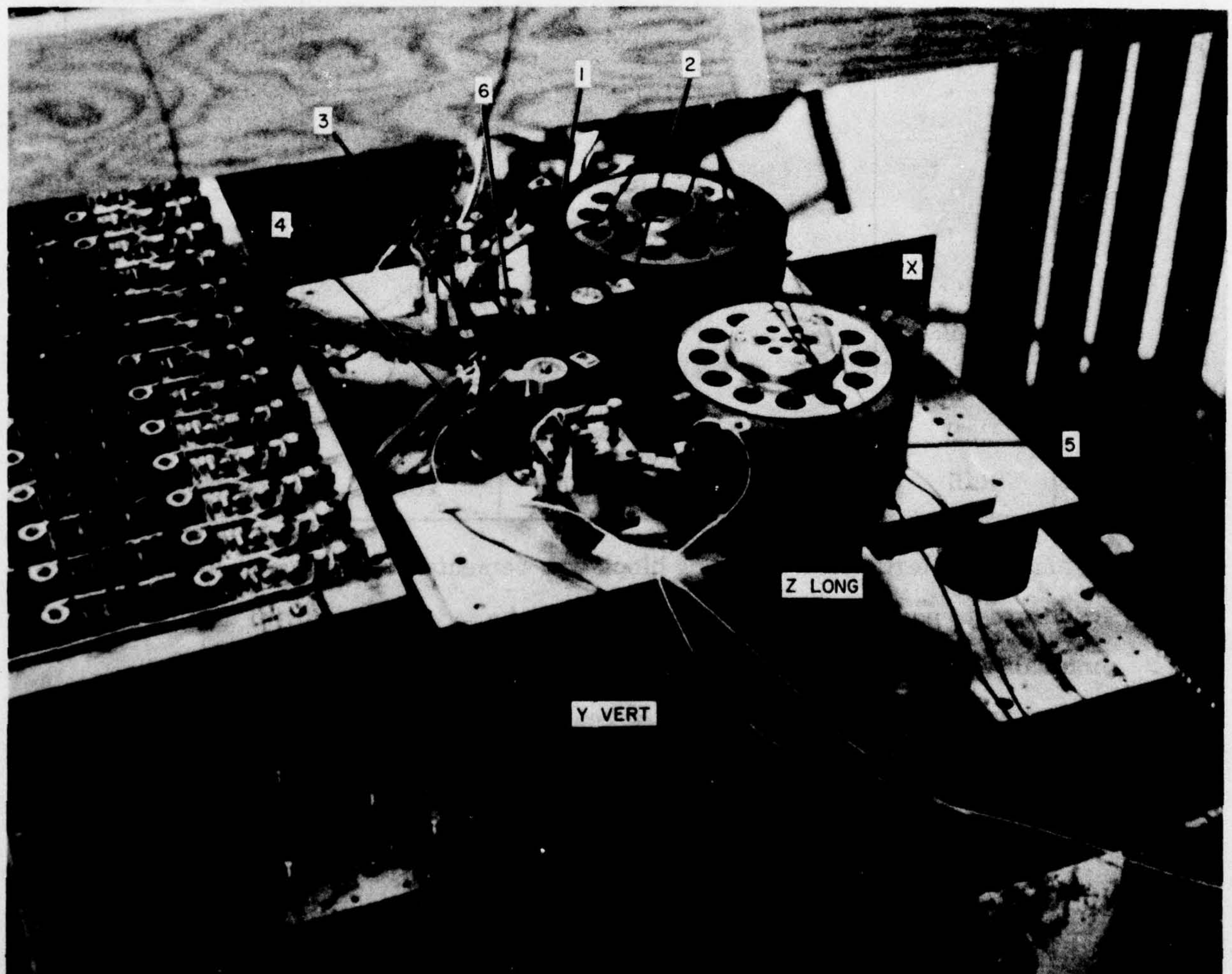


Figure 2-11. Unit 1 Accelerometer Locations and Vibration Axes

Response accelerometers were mounted on Unit 2 transport as follows:

#1. On the deck near the head and guide roller area.

#2. On the end of the right hand guide roller near the head. This roller is typical for the lower level of the tape path.

#3. On the end of the right hand capstan housing.

#4. On the end of the guide roller leading to the upper reel.

#5. On the end of the head.

#6. On the end of one of the left hand pair of rollers comprising the left tape loop sensor. A dummy accelerometer and mount was placed on the other roller for balance.

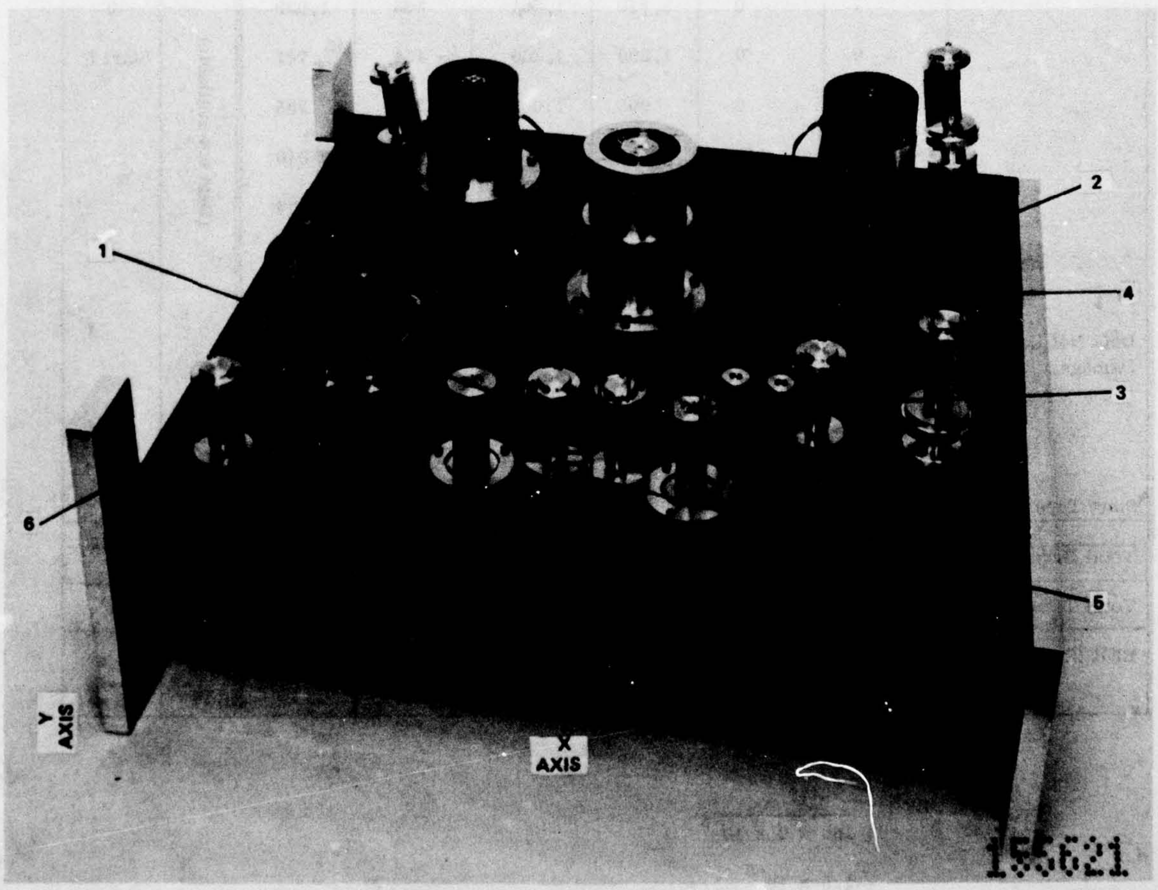


Figure 2-12. Unit 2 Accelerometer Locations and Vibration Axes

TABLE 2-5. BIT ERROR DATA

	Errors/10 Sec. Count (Errors/1000 In. Tape)						Errors/1 Sec. Count	
Track No.	10 & 15		15		10		10 & 15	
Tape Pass No.	1	2	3	6	4	5	*	**
End Tape Pass	34	39	1,095	1,051	1,089	1,337	(Data not available)	End 0
	8	4	2,057	2,303	1,422	864		200
	15	59	1,826	1,650	1,149	1,498		10
	75	59	1,520	1,530	730	641		0
	0	0	1,223	1,457	706	816		20
	6	8	867	827	744	593		10
	7	0	1,570	1,501	806	1,039		0
	0	0	1,290	1,235	454	741		Start 0
	0	0	995	1,053	387	385		
	99	146	2,004	1,803	1,088	640		
	55	48	1,410	1,340	685	614		
	139	99	1,364	1,416	2,202	2,358		
	14	2	1,264	1,375	399	658		
Data Not Used – Damaged Tape –	200,827	200,821	265,097	153,813	171,416	171,102		
	27	43	1,247	1,068	762	1,115		
	0	0	1,327	1,514	765	631		
Start Tape Pass	0	2	1,259	2,853	747	822		
Total Errors	479	509	22,318	23,976	14,135	14,802		240
Total Time Sec.	160	160	160	160	160	160		8
BER (Errors/bit)	1.50×10^{-6}	1.59×10^{-6}	6.97×10^{-5}	7.49×10^{-5}	4.42×10^{-5}	4.62×10^{-5}	2×10^{-5}	1.5×10^{-5}

$$BER = \frac{479}{160 \times 2 \times 10^{-6}}$$

$$= 1.5 \times 10^{-6}$$

*Prior to Vibration Tests

**After 5-2000 Hz Sweep - Nonoperating

heads in parallel, the BER was 1.6×10^{-6} with zero errors occurring for as much as 3000 inches of tape. Differences in error count between tape passes with a single head were 70 percent (448 difference) and less, with one exception. The redundant head error difference was a maximum of 47 percent (47 errors). The error rate range was from 83 to 285 errors/second for individual heads and from zero to 15 errors/second for redundant heads.

2.4.2 VIBRATION

BER test results are included in Table 2-10 under mechanical vibration. Prior to vibration testing the BER was 2×10^{-6}. After the initial .5 g vibration sweep from 5 to 2000 Hz, the BER changed to 1.5×10^{-5}. This was an acceptable level and was used as reference for comparison with BER under vibration conditions.

During the vibration sweep the BER went beyond the 10^{-5} limit in areas of resonance of components and two frequencies (527 and 780 Hz) where there were no component resonances. These were manifested by a two printout and one printout outage, respectively. The maximum BER was 2×10^{-2} at 670 Hz also manifested by one printout. There was also one frequency (723 Hz) where a 10 g capstan resonance (the only resonant component) occurred without a BER exceedance.

During the sweep only between one and three out of limit error printouts occurred at problem frequencies, except at 360 Hz. The data at the resonant frequencies selected for dwell (745, 961, 1742, and 2000 Hz), observed between 6 and 37 seconds, also had only one or two out of limit printouts. The BER at these frequencies was approximately 10^{-5}.

2.4.3 FLUTTER

Nonvibrating and vibrating flutter data for unit 1 is shown in Table 2-6. The largest discrete flutter component was .27 percent at 70 Hz non-vibrating. The largest component due to vibration was .2 percent at 745 Hz.

TABLE 2-6. DISCRETE FLUTTER DATA

Selected Vibration Frequency Hz	Flutter Frequency Hz	Flutter Spectral Percent (%)	Flutter Cumulative $\sqrt{\Sigma (x^2)}$
Non Vibrating	70	0.27	
" "	300	0.05	
" "	820	0.002	.276
" "	6800	0.01	
" "	20000 (10K-30K)	0.02	
358	358	.1	
373	378	.08	
373	746	.06	
591	591	.09	
745	745	.2	.385
961	961	.06	
1742	1742	.06	

The reference flutter data from development transport S/N 1 (non-vibrating) is plotted in Figure 2-13 for discrete data and Figure 2-14 for cumulative data. The largest discrete flutter components were at 50, 800, 1400 and 8200 Hz at .015 percent. The cumulative flutter for frequencies to 20 kHz was .066 percent.

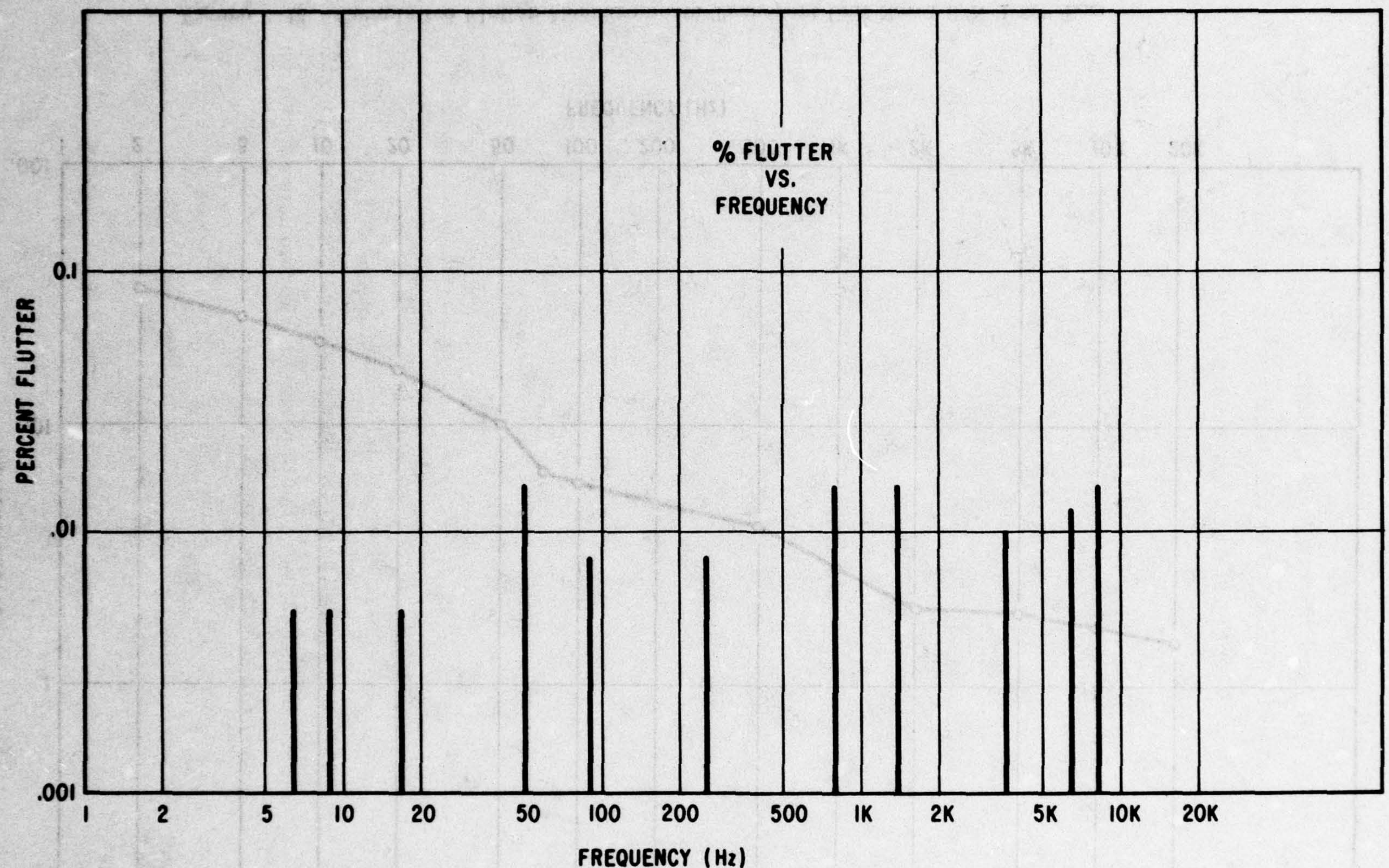


Figure 2-13. Discrete Flutter Components: At 80 In./S Transport Unit No. 1 (S/N-1)

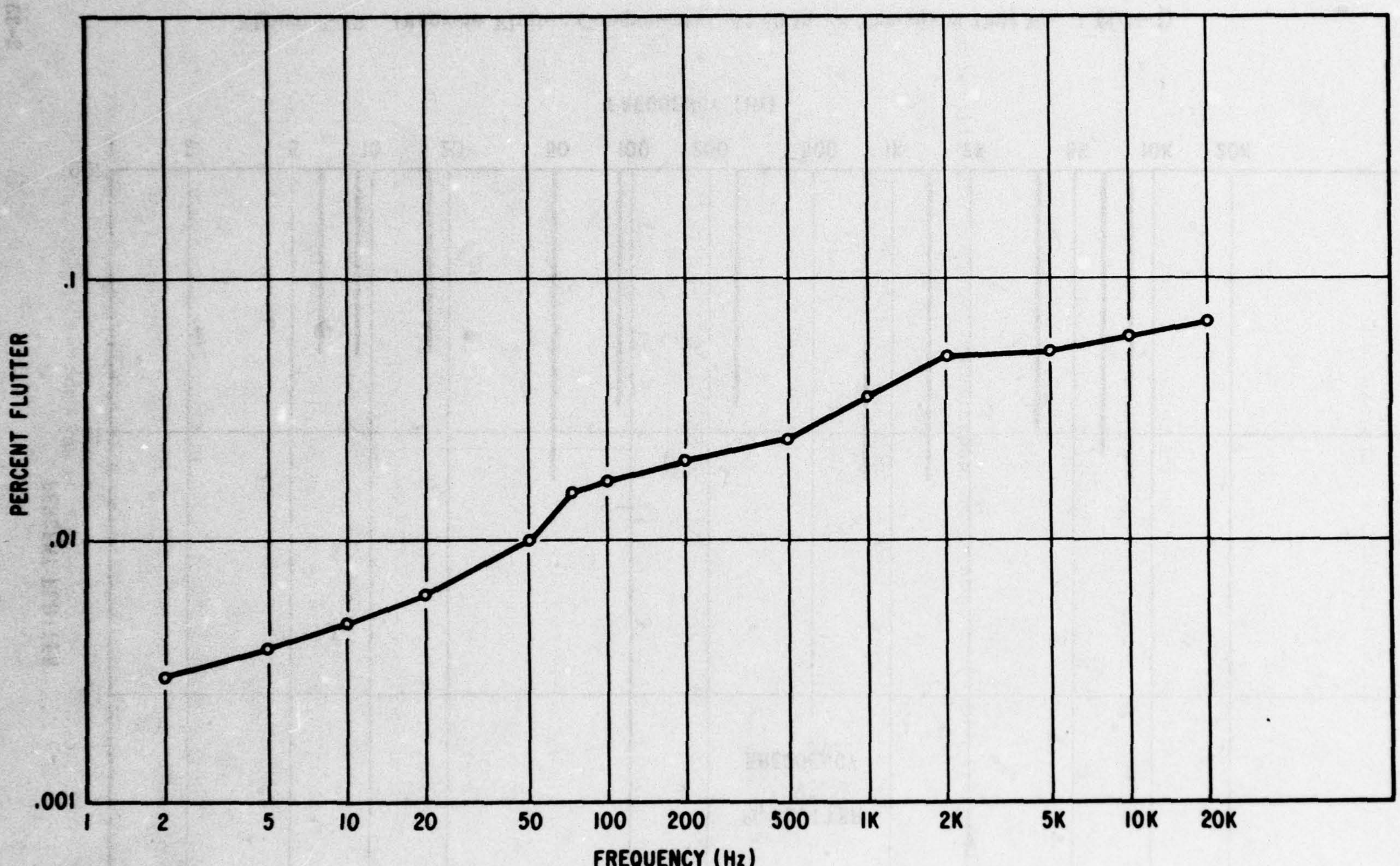


Figure 2-14. Cumulative Flutter Measurements Transport Unit No. 1 S/N-1 80"/Sec

2.4.4 JITTER

Cumulative jitter nonvibrating was approximately:

4 μ Sec p-p hi freq.

6 μ Sec p-p lo freq.

10 μ Sec p-p total variation

The maximum allowable jitter for the required performance is 250 μseconds peak to peak as long as the jitter is within the system bandwidth and adequate buffer storage of approximately 500 bits is provided.

2.4.5 SKEW

Table 2-7 lists nonvibrating skew measurement results. With a bit packing density of 20 Kbpi for the recorders, the bit length is 50 microinches. The 30 microinch maximum edge-to-center skew indicates that all the channels would be within $\pm$0.6 bits of the center channel with this dynamic skew. The most prominent dynamic skew rate of 51 Hz was due to the capstan drive. Figure 2-15 shows the data graphically.

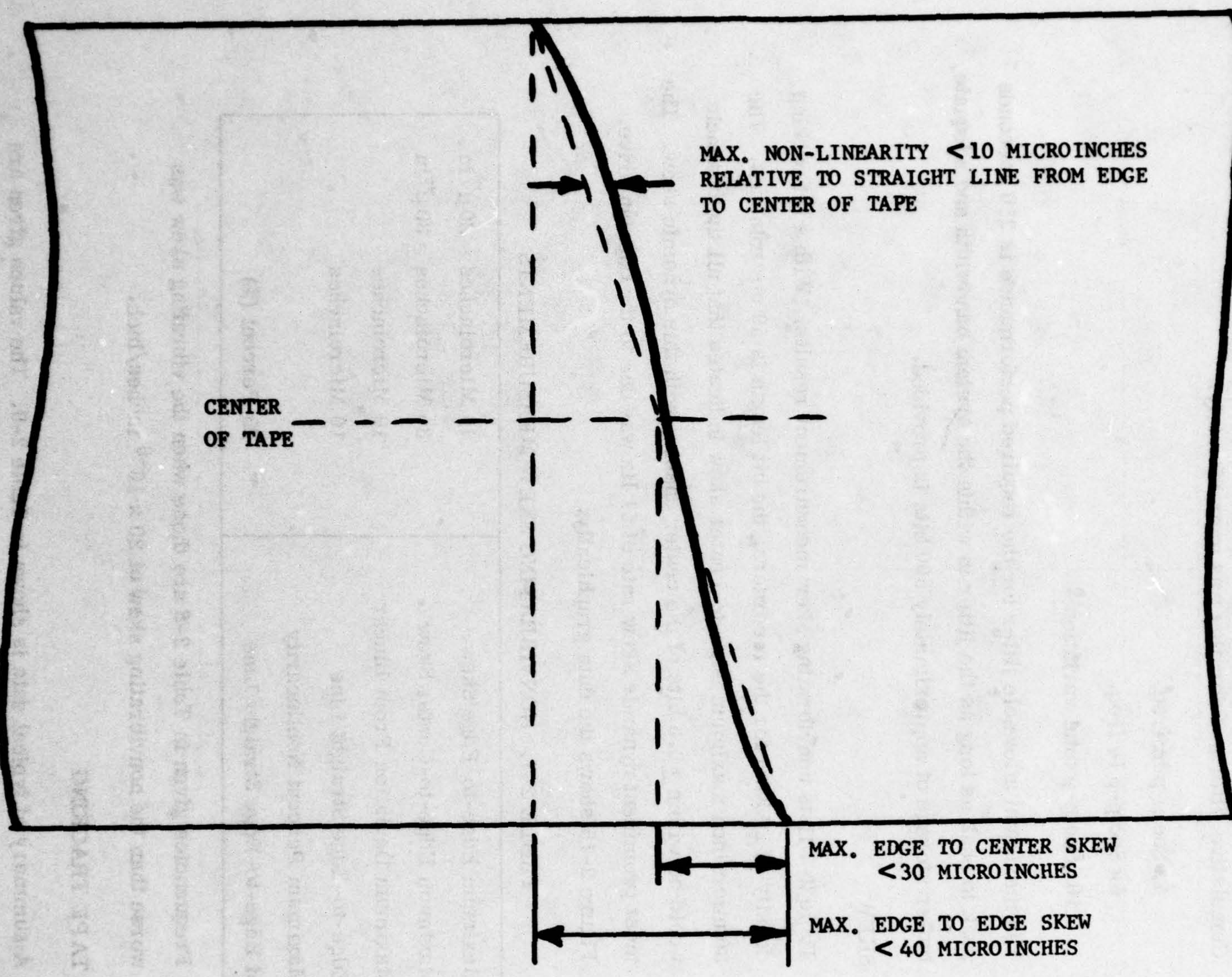
TABLE 2-7. NONVIBRATING SKEW MEASUREMENTS

Maximum Edge-to-Edge Skew	40 Microinches = 20 μ"/in
Maximum Edge-to-Center Skew	30 Microinches = 30 μ"/in
Maximum Deviation From Linear Edge-to-Edge Straight Line	10 Microinches
Edge-to-Edge Straight Line	10 Microinches
Maximum Percent Nonlinearity of Edge-to-Edge Straight Line	25 Percent (%)

Frequencies given in Table 2-8 are those when the vibrating skew was worse than the nonvibrating skew of 20 x 10^{-6} inches/inch.

2.4.6 TAPE TRACKING

A summary of typical data is shown in Table 2-9. The values given are in mils of tracking error. E-ac is the worst case peak-to-peak carrier amplitude or apparent high frequency tracking error. E-dc is the maximum DC tracking error observed at any time during playback.



NOTE: THE MOST PROMINENT SKEW RATE WAS ≈ 51 Hz

Figure 2-15. Skew Measurement Results (Unit #1 Transport)

TABLE 2-8. VIBRATING SKEW MEASUREMENTS

Vibrating Freq. (Hz)	Skew (Microinches/inch)
200	40
277	30
319	30
338	40
389	> 700
420	> 700
443	> 700
474	> 700
600	60
617	>700
700	40
810	40
834	>700
1057	40
1345	40
1670	40
1718	> 700
1769 (1742)	20 to 60
1875	> 700
1933	> 700

TABLE 2-9. TAPE TRACKING ALIGNMENT

Test Condition	Alignment, Mils: Straight Roller E-ac	Straight Roller E-dc	Contour Roller A E-ac	Contour Roller A E-dc	Contour Roller B E-ac	Contour Roller B E-dc
1st Playback/Ambient Temp.	-	-	1.4	2.4	-	-
2nd Playback/Ambient Temp.	1.25	2.0	1.5	2.4	1.5	7.0
3rd Playback/Ambient Temp.	1.25	1.75	-	-	1.5	7.25
1st Playback/35°C	1.25	2.75	1.25	3.0	1.25	8.5
2nd Playback/35°C	1.63	2.75	1.40	2.5	1.25	9.75
3rd Playback/35°C	1.75	3.0	1.25	2.5	1.25	6.25
Vibration, X axis		≈4.0				

AC and DC tracking with the type A and straight rollers were within the allowable 3 mils. Type B roller tracking errors were as high as 9.75 mils.

2.4.7 TAPE TO HEAD SIGNAL TO NOISE RATIO

During qualitative monitoring of tape data on the oscilloscope display, it was observed that the S/N decreased during some resonances. This indicated that tape to head contact deteriorated only during severe resonance problems.

2.4.8 MECHANICAL TEST RESULTS

(1) X AXIS

The peak response data of fixed frequency vibration and sweep tests, along with previbration baseline operating parameters, are summarized in Table 2-10. The data is grouped in narrow frequency bands whose center represent the common frequency of the responses.

Due to the fixturing arrangement of the siderails, the deck had several peak responses from 1.4 to 3.0 g's. The capstan had many resonances with a maximum g level of ten and maximum amplitude of .00135 inch which occurred at different frequencies.

TABLE 2-10. X AXIS PARAMETER DATA AND RESONANCES

Vibration Frequency-Hz		Error Rate Errors per sec.	Error Rate BER	Flutter Flutter freq.	Flutter %	Jitter μs p-p	Skew μ"/"	Tracking Mils	Deck* G/D.A."	Capstan G/D.A."	Head G/D.A."	Roller G/D.A."	Motor G/D.A."	Diam. Sensor G/D.A."	Observations
Non Vib.			2×10^{-6}	70	0.27	10	30	1.25 to 2.0							
				300	0.05										
				820	0.002										
				6800	0.01										
				10K-30K	0.02										
Nom. Vib. Center f	After Accel. Sweep Range f		1.5×10^{-5}												
-	5 to 320	390	2×10^{-4}			Not Measured During Vibration	40	Visual Scope Observation During Vibration Max. of 4.0	1.4/.00027	2/.00135	1.7/.00103		2.3/.00155	1.5/.00101 2.0/.00063	Audible Noise
360	330 to 390	14990	2×10^{-3}	358	0.1		≥700		1.4/.00024	5.2/.00070	4.2/.00057	15/.0026	2.2/.00038	10/.00151	Irregular Tape Stacking .032" @5 layers roller Motion Visible by Strobe lite
450	420 to 480						≥700							4/.00043	
527	530 to 535	4830	2×10^{-3}												
575	558 to 591	11510	6×10^{-3}	591	0.09				3/.00019	8.4/.00052	5.4/.00031	2.9/.000176	6/.00041	4/.00025	
617	617						≥700			3 Not peak /.00015					
670	660 to 680	39390	2×10^{-2}						1.7/.00008	4 Not peak /.00018	5/.00021		4.5/.00019	1.3/.00006	
723	700 to 745		3×10^{-5}	745	0.2		40			10/.00034		1.2/.00005			
800	780 to 810	390	2×10^{-1}				40								
835	830 to 840	380	2×10^{-1}				≥700			5/.00001	3/.00008	1.1/.00003	9/.00025		
970	960 to 980	1200	6×10^{-1}	961	0.06						4.8/.00010				
1360	1050 to 1670	1070	5×10^{-4}				40			2.7/.00002	3.2/.00005		4.8/.00005	0.9/.00001	
1710	1700 to 1718	810	4×10^{-4}				≥700			10.5/.00007					
1940	1875 to 2000	310	1.6×10^{-4}				≥700			5.8/.00003	3.4/.00002			2.9/.00001	

*G/D.A." = Acceleration (G level)/Displacement Amplitude in Inches (Peak to Peak)

The roller had several resonances with a maximum g level of 15 and maximum amplitude of .0026 inch which occurred at the same frequency. The motor had many resonances with a maximum g level of 9 and a maximum amplitude of .00155 inch which occurred at different frequencies. The diameter sensor had many resonances, with a maximum g level of 10 and a maximum amplitude of .0015 inch which occurred at the same frequency (360 Hz). In this frequency range there occurred irregular tape stacking on the take-up reel of approximately 1/32 inch from below to above the normal stacking plane for approximately five layers of tape.

(2) Y AXIS

The Y axis acceleration and amplitude responses are given in Table 2-11. The deck had several resonances. Two prominent ones were in the range of 250 Hz and 500 Hz. The maximum accelerations were 3.5 g and 6 g respectively. The maximum amplitude was .00110 inch at the lower frequency.

The response of all the elements, except the capstan, closely followed the deck responses in the range of 250 Hz and 500 Hz. The following discussions refer to component responses which were independent of deck response.

The capstan followed the 250 Hz deck response with some amplification but it was decoupled from the 500 Hz response. The maximum g level was 3.6 and the maximum displacement was .00154, occurring at different frequencies. The head had one resonance of 3.2 g and .00003 inch amplitude, both at the same frequency. The roller head had a maximum g response of 6.5 and .00009 inch amplitude both at the same frequency. The motor had two independent responses.

TABLE 2-11. Y-AXIS RESONANCES - TRANSPORT UNIT 1

Transport Element	Principal Resonant Freq's, Hz.	Accel'n. G's	Calculated Displacement P-P, Inches
Guide Roller	245	4.0	.00130
	500	9.5	.00074
	* 830	2.0	.00006
	*1380	6.5	.00007
	1830	6.7	.00004
Motor	245	5.3	.00173
	280	7.8	.00195
	500	3.7	.00029
	* 850	2.1	.00006
	*1350	5.0	.00005
	*1700	3.6	.00002
Head	245	3.6	.00117
	275	4.6	.00119
	500	7.4	.00058
	1000	2.3	.00004
	*1350	3.2	.00003
Deck	250	3.5	.00110
	280	2.9	.00072
	500	6.0	.00047
	1000	1.6	.00003
	2000	2.1	.00001
Sensing Arm	245	5.2	.00169
	275	3.2	.00083
	500	3.7	.00029
	* 800	1.4	.00004
	1900	3.8	.00002
Capstan Housing	* 185	2.7	.00154
	230	5.2	.00192
	280	6.3	.00157
	* 800	3.6	.00011
	*1400	2.2	.00002
	1900	1.5	.00001

*RESONANCES OCCURRING INDEPENDENTLY OF DECK RESONANCE

The maximum g level was 5.0 and the maximum amplitude was .00006 occurring at different frequencies. The diameter sensor had one independent resonance. The g response was 1.4 and the amplitude was .00029 inch.

Transport operating parameters were not measured in the Z axis.

(3) Z AXIS

The Z axis acceleration and amplitude responses are given in Table 2-12. The fixturing arrangement in this axis was generally better than in the X axis. Several small peaks occurred in the deck response of 1.1 to 2.2 g's. In addition, a decoupling occurred in the range of 800 to 1200 Hz. The capstan had two resonances with a maximum g level of 44 Hz and maximum amplitude of .0039 inch both at the same frequency. The head had several response peaks with the maximum g level of 12.8 and maximum amplitude of .00076 inch which occurred at different frequencies. The roller head had several response peaks with a maximum g level of 9.7 and maximum amplitude of .00115 inch which occurred at different frequencies. The motor had several response peaks with a maximum g level of 4.4 and a maximum amplitude of .00049 inch which occurred at different frequencies. The diameter sensor had several resonances with a maximum g level of 0.2 and maximum amplitude of .00075 inch which occurred at different frequencies.

TABLE 2-12. Z-AXIS RESONANCES TRANSPORT UNIT 1

Transport Element	Principal Resonant Freq's, Hz.	Accel'n. G's.	Calculated Displacement P-P, Inches
Guide Roller	170	1.7	.00115
	340	3.8	.00064
	975	6.3	.00013
	1070	6.8	.00012
	1600	9.7	.00007
Motor	350	3.1	.00049
	475	3.6	.00031
	520	4.4	.00032
Head	183	1.3	.00076
	350	3.2	.00051
	470	3.3	.00029
	620	6.8	.00035
	720	12.8	.00048
Deck	340	1.1	.00019
	600	1.2	.00007
	(800-1200)	(0.2)	4×10^{-6}
	1700	2.4	.00002
Sensing Arm	180	1.2	.00072
	360	3.0	.00045
	460	2.3	.00021
	490	2.4	.00020
	1850	8.2	.00005
Capstan Housing	470	44.0	.00390*
	1720	11.5	.00008*

*Motion Visible by Strobe Light

2.5 UNIT 2 TEST RESULTS

2.5.1 BER MEASUREMENTS

BER test results are included in Table 2-20 under X axis mechanical vibration. Prior to vibration testing the BER was 4×10^{-4}. During the resonant dwells the BER increased at three frequencies, 230, 350, and 440 Hz. Maximum BER was 1×10^{-1}; the other two were approximately 3.5×10^{-3}. Error printouts were consistent during these frequency dwells unlike unit 1 where a few high errors occurred mostly among very low values.

2.5.2 FLUTTER

Nonvibrating and vibrating percent discreet flutter data are given in Table 2-13. Calculated cumulative percent flutter is also given.

The largest discrete nonvibrating flutter was 0.03 percent at 80 Hz. The largest discrete flutter during vibration was 0.16 percent at 728 Hz. Cumulative flutter was 0.03 percent nonvibrating and 0.21 percent under vibration.

2.5.3 JITTER

Jitter data, both vibrating and nonvibrating, is given in Table 2-14. During vibration at each resonant frequency, no increase in jitter occurred from the 8 microseconds peak to peak nonvibrating value.

2.5.4 SKEW

(1) CUMULATIVE DATA

Total cumulative dynamic nonvibrating skew measured by observing the center and outer edge tracks on an oscilloscope was:

Lo freq. dynamic skew, 1 μs @ 100 in/s = 100 μ IN

Hi freq. dynamic skew, 1 μs @ 100 in/s = 100 μ IN

TOTAL dymanic skew = 200 μ IN PEAK = 100 μ inches/inch

TABLE 2-13. FLUTTER DATA UNIT 2

Fixed Vibration Frequency (Hz)	Flutter Frequency (Hz)	Flutter Spectral (%)	Flutter Cumulative $\sqrt{\Sigma (X^2)}$ (%)
Engineering Lab. Data			
Nonvibrating	80	.03	
Nonvibrating	340	.008	
Nonvibrating	1400	.005	.032
Nonvibrating	4200 (Intermittent)	.005	
Vibration Lab. Data			
Nonvibrating	10	.009	
Nonvibrating	40	.017	
Nonvibrating	80	.024	.031
Nonvibrating	320	.002	
Nonvibrating	400	.002	
279	279	.07	
354	354	.05	
431	431	.02	
686	686	.08	.212
686	728	.04	
728	728	.16	
861	861	.04	
915	915	.05	
1603	1603	.03	

TABLE 2-14. JITTER

Fixed Vibration Frequency (Hz)		Absolute Jitter (μs p-p)
Nonvibrating		8*
278		6
354		5
686		6
728		5
915		8
1604		8

*4μ Sec p-p high frequency + 4μ Sec p-p low frequency = 8μ Sec p-p

(2) SPECTRAL DATA

Dynamic nonvibrating skew versus skew frequency is given below:

TABLE 2-15. DYNAMIC SKEW NONVIBRATING

(Taken in Engineering Laboratory)

Approximate Skew Frequency (Hz)	Dynamic Skew (Microinches)		
	Center To Outer Edge	Center To Inner Edge	Outer To Inner Edge
40	8	8	13 (7/IN)
50	5	2	9 (5/IN)
90	2	2	2.8 (1.4/IN)
120	1.4	2	2.8 (1.4/IN)
130	<1	1.4	3 (1.5/IN)
340	2	1.2	3 (1.5/IN)

Dynamic skew was monitored during the vibration sweep from 5 to 2000 Hz. Nonvibrating skew of 100 x 10^{-6} inches/inch was not noticeably exceeded at any time.

(3) CUMULATIVE DATA — VIBRATING

Total cumulatative dynamic skew measured by observing the center to outer track (one inch) timing error on an oscilloscope. Visual observation given this measurement to 2 γ maximum.

	Nominal Peak	Worst Case (At Some Resonances)
Lo freq. dynamic skew	1-1/2 μs	2
Hi freq. dynamic skew	1/2 μs	1
Total dynamic skew	2 2 μSec	3 μSec

3 μs @ 100 in/s = 300 x 10^{-6} inches/inch worst case dynamic skew during 0.5g vibration. There was no skew problem at this g level.

(4) SPECTRAL DATA — VIBRATING

Spectral skew measurements during vibration are given below:

TABLE 2-16. DYNAMIC SKEW VIBRATING

Vibration Frequency Hz	Skew Frequency Hz	Skew μ inches/inch
Nonvibrating	40	8
Nonvibrating	50	5
Nonvibrating	90	2
Nonvibrating	120	1.4
Nonvibrating	130	4
Nonvibrating	340	2
285	285	4.2
356	356	.9
431	431	.3
686	686	.4
728	728	1.3
861	861	.7
915	915	.8
1603	1603	8.4

2.5.5 TAPE TRACKING

The recorded signal from the optical tracking sensor consists of an AC carrier of various frequencies which changes its average position with tape movement (DC tracking error). The largest peak to peak AC components can be attributed to tape width variations, edge curvature, and edge damage. Emphasis should be placed on DC tracking error either inherent in the transport (long term end to end) or vibration induced (short term).

Previbration tracking error baseline recording and the vibration mounting check for the optical sensor proved to be practically the same for all three axes. Typical AC tracking error was .0015 inches peak to peak while DC tracking error was .002 inches end to end. The sensor mount performed satisfactorily in all three vibratory directions producing no erroneous tracking indications.

The following tables 2-17, 2-18, and 2-19 give tracking data for the three vibration axes at frequencies where there was 2 mils or greater DC tracking error. Acceleration and peak to peak displacement (D.A.) of responsive transport components are also given. Location of the control accelerometer when recording tracking data is given. In the X axis additional acceleration data (indicated by *) was taken without recording tape tracking data.

2.5.6 SIGNAL TO NOISE RATIO

Qualitative observations of BER data signal level on the oscilloscope showed no change during nonvibrating or vibrating conditions.

2.5.7 MECHANICAL TEST RESULTS

Maximum acceleration and peak to peak displacements (D.A.) at resonances of transport components are given for .5g vibration input in Tables 2-20, 2-21, and 2-22. Two sets are given for the X axis, one with the input control on the side rail when all parameter data was also taken, and one with the control at

TABLE 2-17. MAXIMUM VIBRATION INDUCED TRACKING ERROR - X AXIS

Vibration Frequency Hz	DC Error Mils	Upper Guide Roller				Tape Loop Sensor				Deck	
		Rail Control		*Deck Control		Rail Control		*Deck Control		*Rail Control	
		G	D.A. mils	G	D.A. mils	G	D.A. mils	G	D.A. mils	G	D.A. mils
230	⊛3.0	6.4	2.4	1.3	.5	4.0	1.5	†1.3	†.5	1.5	.6
275	1.5	12.0	3.5	1.2	.3	11.0	2.7	2.8	.7	2.9	.7
340-380	⊛3.0	17	2.6	3.0	.5	13.0	2.3	5.8	1.0	1.3	.2
450	⊛2.0	17	1.8	3.4	3.6	1.7	.2	3.1	.3	.4	.04

⊛ BER also out of limit.

* Additional vibrating data with control at Deck Location (no tracking data at this condition)

† Not a peak

D. A. = Displacement Amplitude in mils (10^{-3} inches) (Peak to Peak)

TABLE 2-18. MAXIMUM VIBRATION INDUCED TRACKING ERROR - Y AXIS

Vibration Frequency Hz	DC Error Mils	Upper Guide Roller		Deck		Reel System
		Rail Control		Rail Control		Rail Control
		G	D.A. mils	G	D.A. mils	Visual Motion
100-140	2	1.3	1.3	4.6	4.6	Yes
160	2	0.14	.1	1.1	.8	--
240	2	--	--	1.4	.5	--

TABLE 2-19. MAXIMUM VIBRATION INDUCED TRACKING ERROR - Z AXIS

Vibration Frequency Hz	DC Error (Mils)	Upper Guide Roller Deck Control G	Upper Guide Roller Deck Control D.A. mils	Tape Loop Sensor Deck Control G	Tape Loop Sensor Deck Control D.A. mils	Capstan Deck Control G	Capstan Deck Control D.A. mils	Head Deck Control G	Head Deck Control D.A. mils
250	2.0	3.3	1.0	3.4	1.0				
285	2.0			2.4	.6				
340-400	2.0			12.5	2.4	32.0	5.1		
435	7.0	47.0	4.9	3.2	.3				
950	3.0							14.5	3.6
1100	3.0	--	--	--	--	--	--	--	--

D. A. = Displacement Amplitude in Mils (10^{-3} inches) (Peak to Peak)

the deck for obtaining comparative data simulating the effect of a stiffer deck fixture arrangement.

Since each component had various responses of interest which were isolated in previous sections and since major resonances can be selected from response Tables 2-21, 2-22, and 2-23, it is unnecessary to highlight them again in this section.

TABLE 2-20. TRANSPORT UNIT Z PARAMETER DATA AND X AXIS RESONANCES CONTROL (SEE NOTE)

Vibration Frequency Hz: Center	Range	BER	Flutter: Flutter Freq.	Flutter: %	Jitter $M_s P_k - P_k$	Skew Freq.	μ"/in	Tracking Error Mils	Capstan G/D.A."	Head G/D.A."	Lower Roller G/D.A."	Upper Roller G/D.A."	Loop Sensor G/D.A."	Deck G/D.A."	Note:
Non Vibrating		$4x10^{-4}$	10 40 80 320 400 1400 4200	0.009 0.017 0.024 0.002 0.002 0.005 0.005	8	40 50 70 120 130 340	8 5 2 1.4 < 1 2	3							Control on rail, ( )-indicates accelerometer-only data taken, with control on deck.
230	230	$1x10^{-1}$						3	2.2/0.00081			6.4/0.00236	4/0.00148	1.5/0.00055	
260	250 to 270	No effect							3.1/0.00097				3.4/0.00098		
280	278 to 285	$3.9x10^{-4}$	278	0.07	6	285	4.2	1.5	3.1/0.00090	3.1/0.00077	3.3/0.00083	12/0.00347	11/0.00274 2.5/0.00062	2.9/0.00072	
350	340 to 360	$2.5x10^{-3}$	354	0.05	5	356	.9	3	5.5/0.00088	2.2/0.00037	2.2/0.00036	17/0.00263	13/0.00233 5.8/0.00098	1.3/0.00022	
440	430 to 450	$4.1x10^{-3}$	431	0.02		431	.3	2				17/0.00180 34/0.00359	3.1/0.00032		
715	686 to 740	$6.2x10^{-4}$	728	0.16	3.5	728	1.3		9/0.00033 1.0/0.00069		2.1/0.00008 3.0/0.00011	2.8/0.00011			
860	810 to 915	$4.2x10^{-4}$	915	0.05	5.8	915	.8				3.1/0.00008 14/0.00042	2.5/0.00007	4.8/0.00013		
935	920 to 950	No effect							2.7/.00006				2.9/0.00006 8.5/0.00019		
1420	1420	No effect							2.6/0.00003	4.6/0.00004 14/0.00014			4/0.00003		
1615	1550 to 1680	$4.9x10^{-4}$	1603	0.03	8	1603	8.4		4.8/0.00003	15/0.00011 6.5/0.00005	7.5/.00005 7.5/0.00006	12/0.00009 4/0.00003	11/0.00024 26/0.00019	1.1/.00001	
1765	1750 to 1780	No effect								4.6/0.00003		11/0.00066 32/0.00020			

*G/D. A." = Acceleration (G level)/Displacement Amplitude in Inches (Peak to Peak)

TABLE 2-21. TRANSPORT UNIT 2 TAPE TRACKING DATA AND Z AXIS RESONANCES (CONTROL ON DECK)

Vibration Frequency (Hz)		Tracking Error	Capstan	Head	Lower Roller	Upper Roller	Loop Sensor
		(Mils)	G/D.A."	G/D.A."	G/D.A."	G/D.A."	G/D.A."
Center	Range						
250	230 to 260	2				3.3/0.00122	3.4/0.00098
285	285	2					2.4/0.00058
370	330 to 400	2	32/0.00510		2.1/0.00030		12.5/0.00242
435	435	7				47/0.00485	3.2/0.00032
640	550 to 730	No Effect	3/0.00011	2.2/0.00015	2.8/0.00008	2.9/0.00019	2.6/0.00011
900	850 to 950	3		14.5/0.00036	36/0.00097		4.8/0.00013
1075	1050 to 1100	3			2.2/0.00004		
1360	1300 to 1420	No Effect		2.6/0.00003		7/0.00007	
1550	1500 to 1600	No Effect		3/0.00002	10/0.00018		7/0.00006
1730	1730	No Effect				12/0.00008	

G/D.A." = Acceleration (G level) /Displacement Amplitude in Inches (Peak to Peak)

TABLE 2-22. TRANSPORT UNIT 2 TAPE TRACKING DATA AND Y AXIS RESONANCES (CONTROL ON SIDE RAIL)

Vibration Frequency (Hz) Center	Vibration Frequency (Hz) Range	Tracking Error (Mils)	Capstan G/D. A.	Head G/D. A.	Lower Roller G/D. A.	Upper Roller G/D. A.	Loop Sensor G/D. A.	Deck G/D. A.
	100	2						
122	122	2	3.3/0.00433	4./0.00525	3.6/0.00472	1.2/0.00157	3.4/0.00462	3.6/0.00472
150	140	2	4.1/0.00409	4.8/0.00478	4.6/0.00458	1.3/0.00129	3.8/0.00379	4.6/0.00458
	160	2						
	240	2						
250	260		1.5/0.00043	1.9/0.00055	1.6/0.00046		2.1/0.00061	1.4/0.00040
515	480 to 550		1.6/0.00010	1.5/0.00010			2.9/0.00019	
800	800				5.2/0.00016			
1300	1300			1.9/0.00002		2.7/0.00003		2.1/0.00002
1420	1420					2.3/0.00002		
1575	1550 to 1600			1.9/0.00002	2.7/0.00002		1.8/0.00001	2.3/0.00002
1750	1750					3.2/0.00002		

G/D. A." = Acceleration (G level)/Displacement Amplitude in Inches (Peak to Peak)

2.6 TEMPERATURE AND ALTITUDE TEST RESULTS

2.6.1 BER MEASUREMENTS

BER test results over the temperature range of -5°C to +50°C and at +30°C plus an altitude of 70,000 feet (1.3 inches of Hg) are included in Figure 2-16. The BER was measured at -18 db threshold level and for dropouts longer than 48 μ sec. These limits were determined by the adapability of the EDAC being able to best perform within them. The BER deteriorates slightly at the upper and lower temperature limits for both tapes tested. The BER remained constant at both sea level and at the 70,000 feet level. Eight various tapes in Figure 2-17 indicate the degradation of S/N as the dropout rate requirement becomes more stringent.

2.6.2 FLUTTER

Tape velocity variations cause data frequency changes that effect the stability of the output data, and is called flutter. One of the contributing items to the overall flutter is the mechanical stability of the tape. The tape base material is complient and changes properties with mechanical and thermal stress. The flutter shown in Figure 2-18 and Figure 2-19 is a composit value of contributions of the tape changes and the transport changes. The 3M 361 tape indicates slightly higher values than the Ampex 799 tape and is probably due to its 10% thinner base material. Altitude changes do not effect flutter. The flutter profiles of both tapes peak near the end of 160 second data run. The maximum measured values are well below the 1% required goal.

2.6.3 JITTER

Timing error is a function of the integrated value of flutter over the period of time between pulses and is called jitter. Jitter is shown in Figure 2-20 and Figure 2-21. Again, the 3M 361 tape indicates a wider spread of data than the Ampex 799 tape. Altitude changes do not effect jitter. The flutter profile

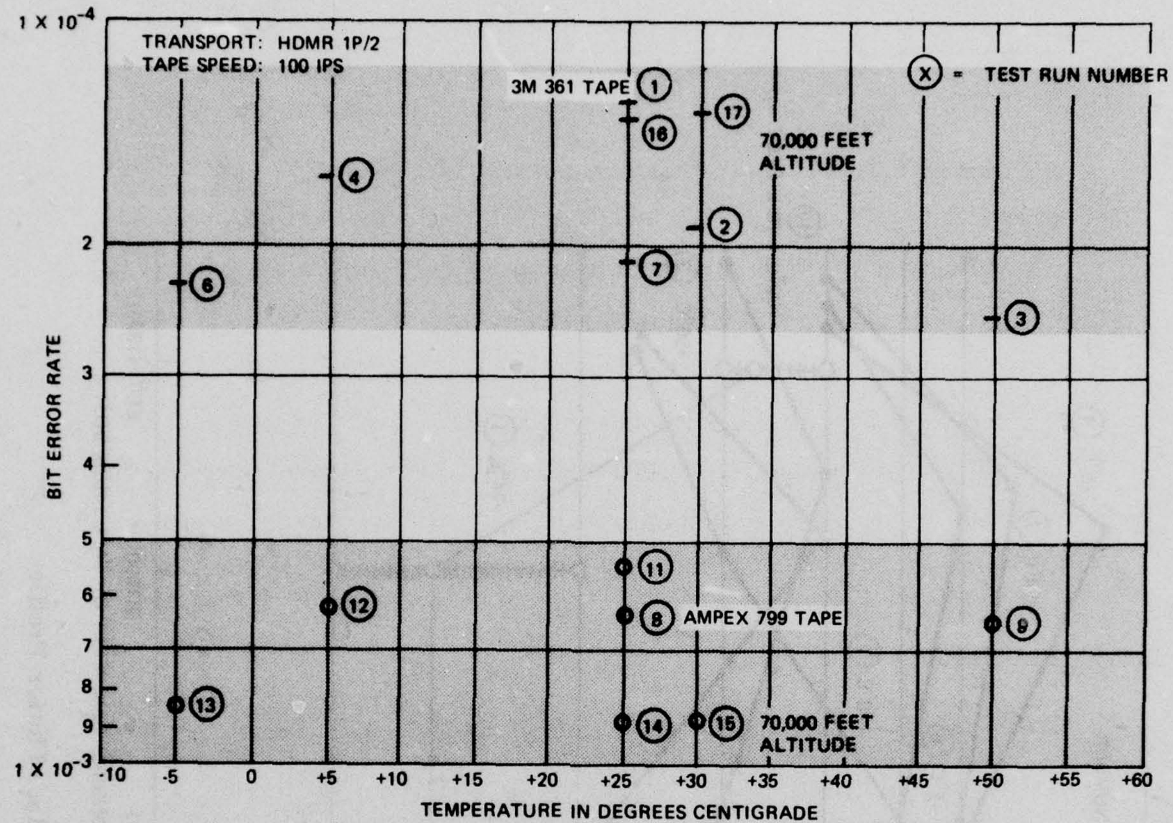


Figure 2-16. BER Profile

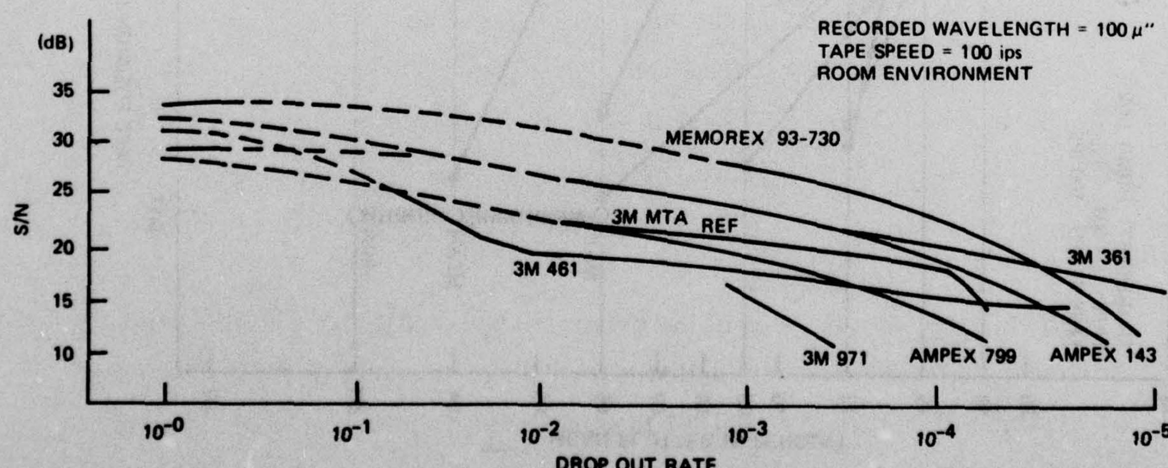


Figure 2-17. Drop Out Rate vs Tape S/N Level

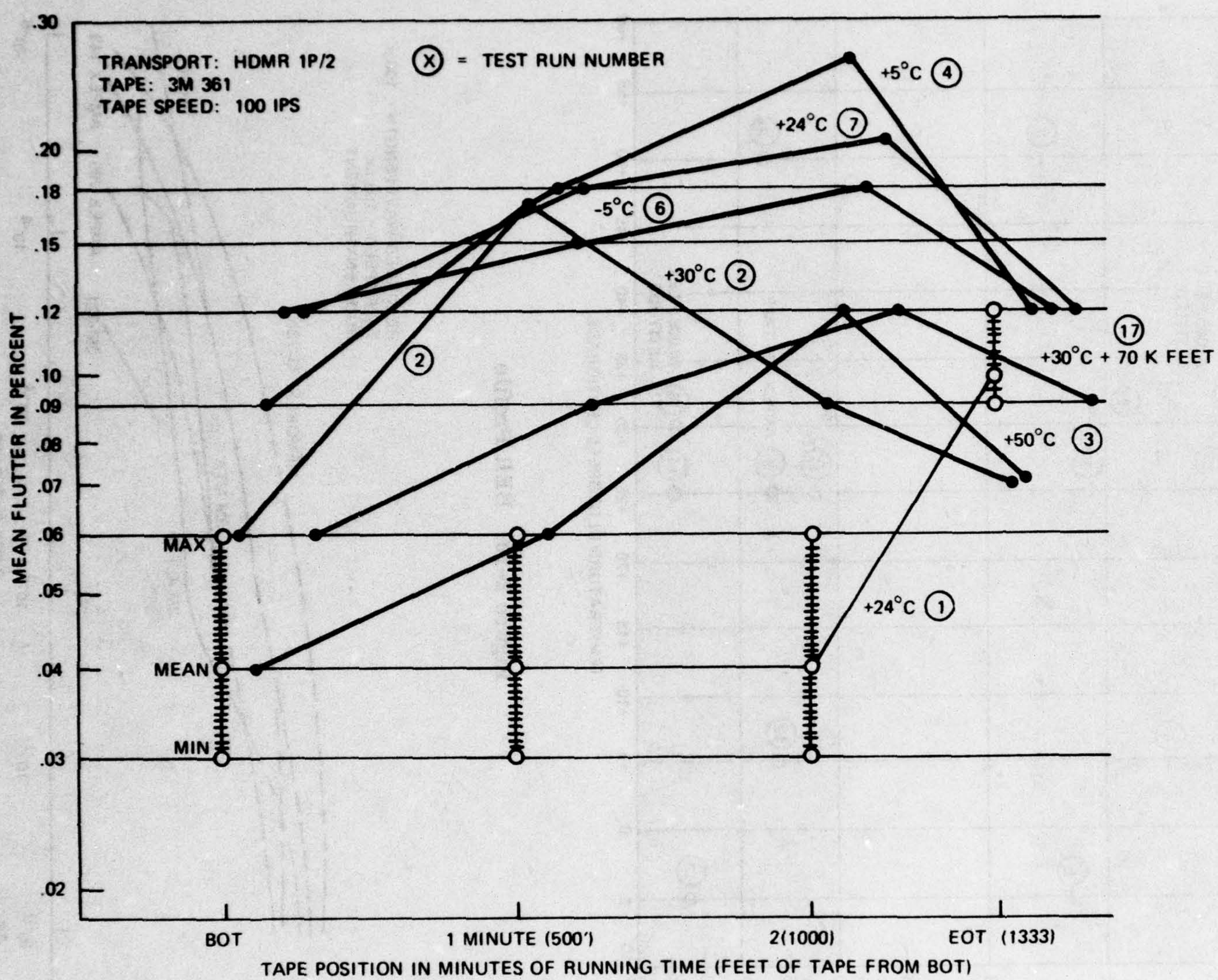


Figure 2-18. Flutter Profile

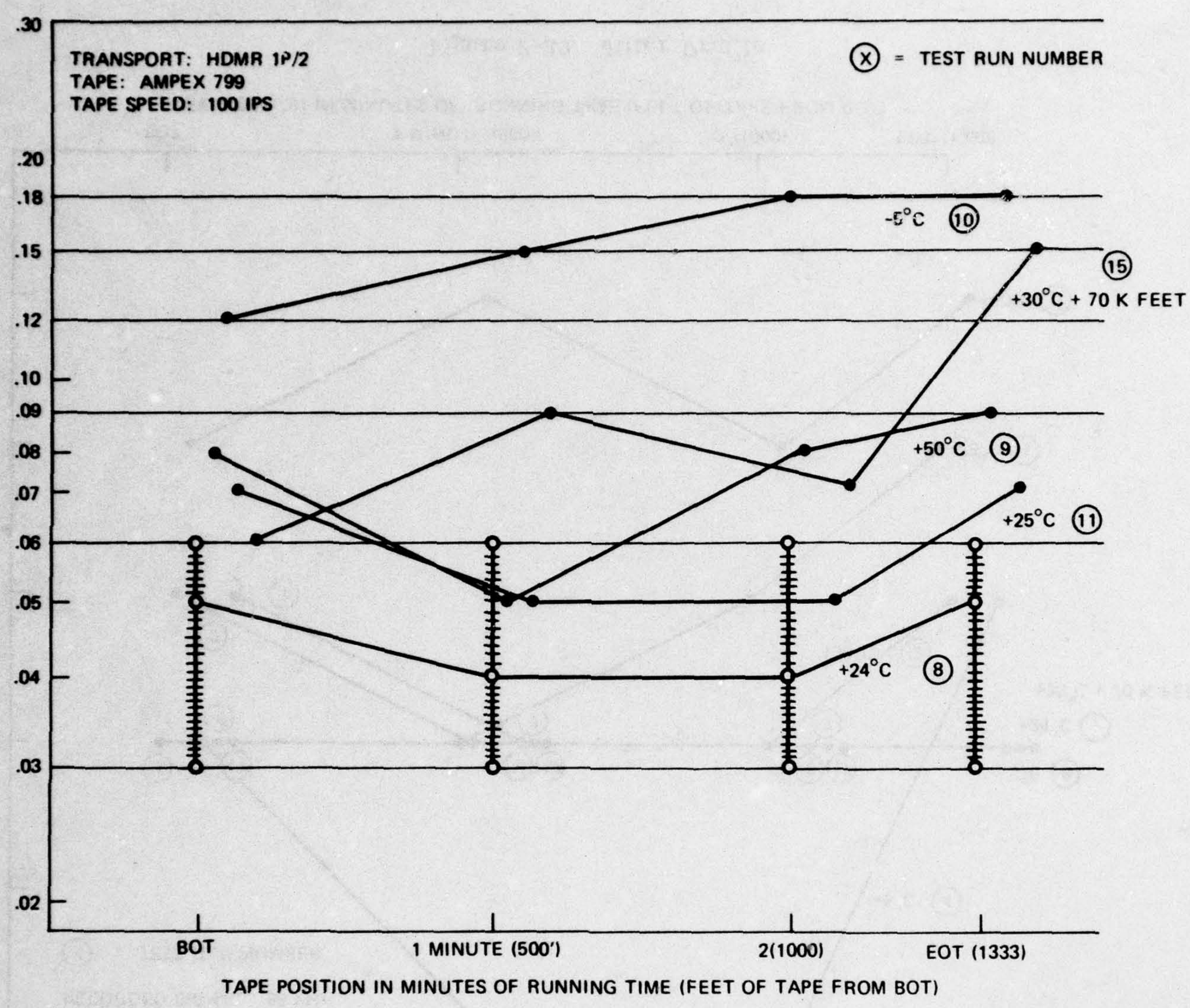


Figure 2-19. Flutter Profile

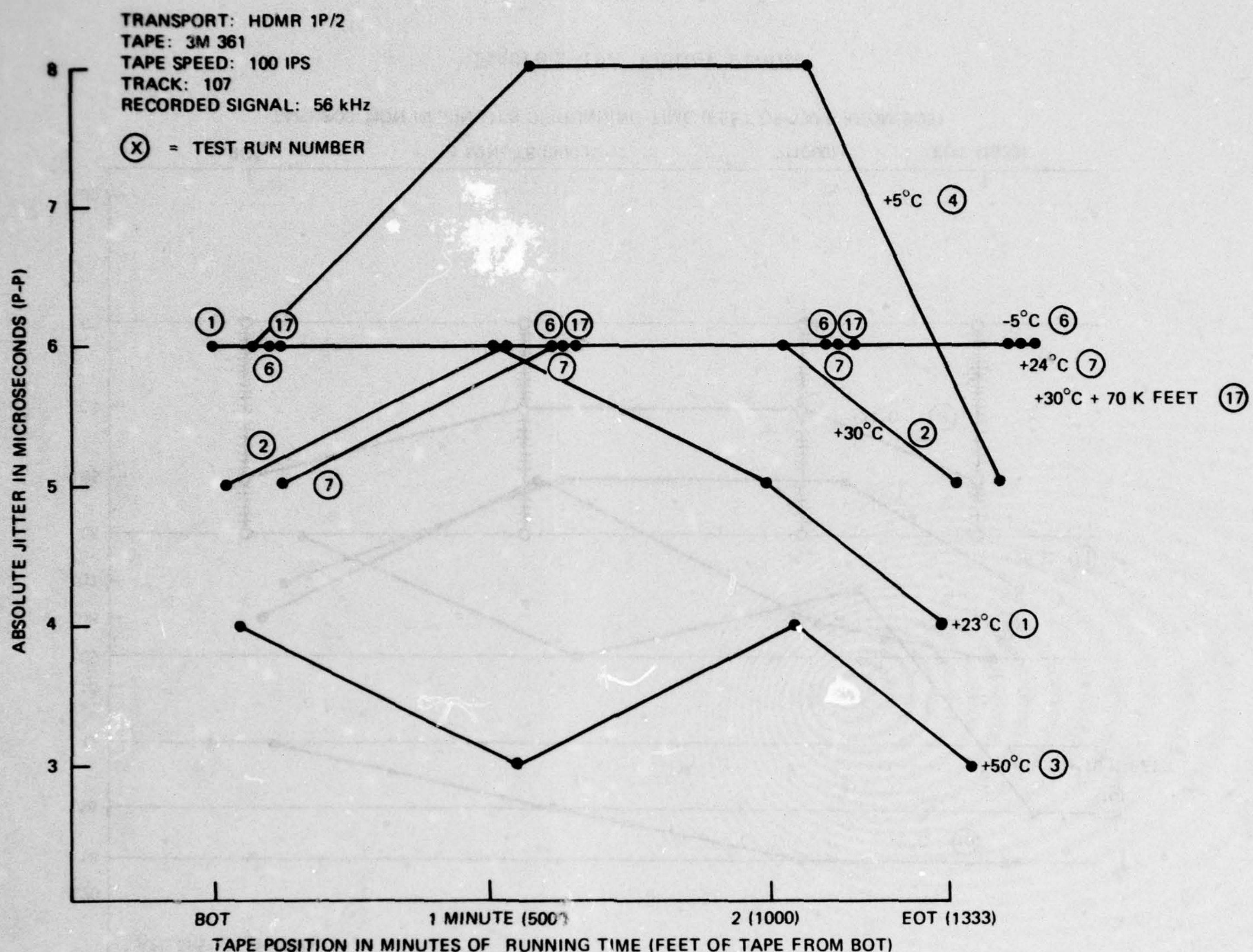


Figure 2-20. Jitter Profile

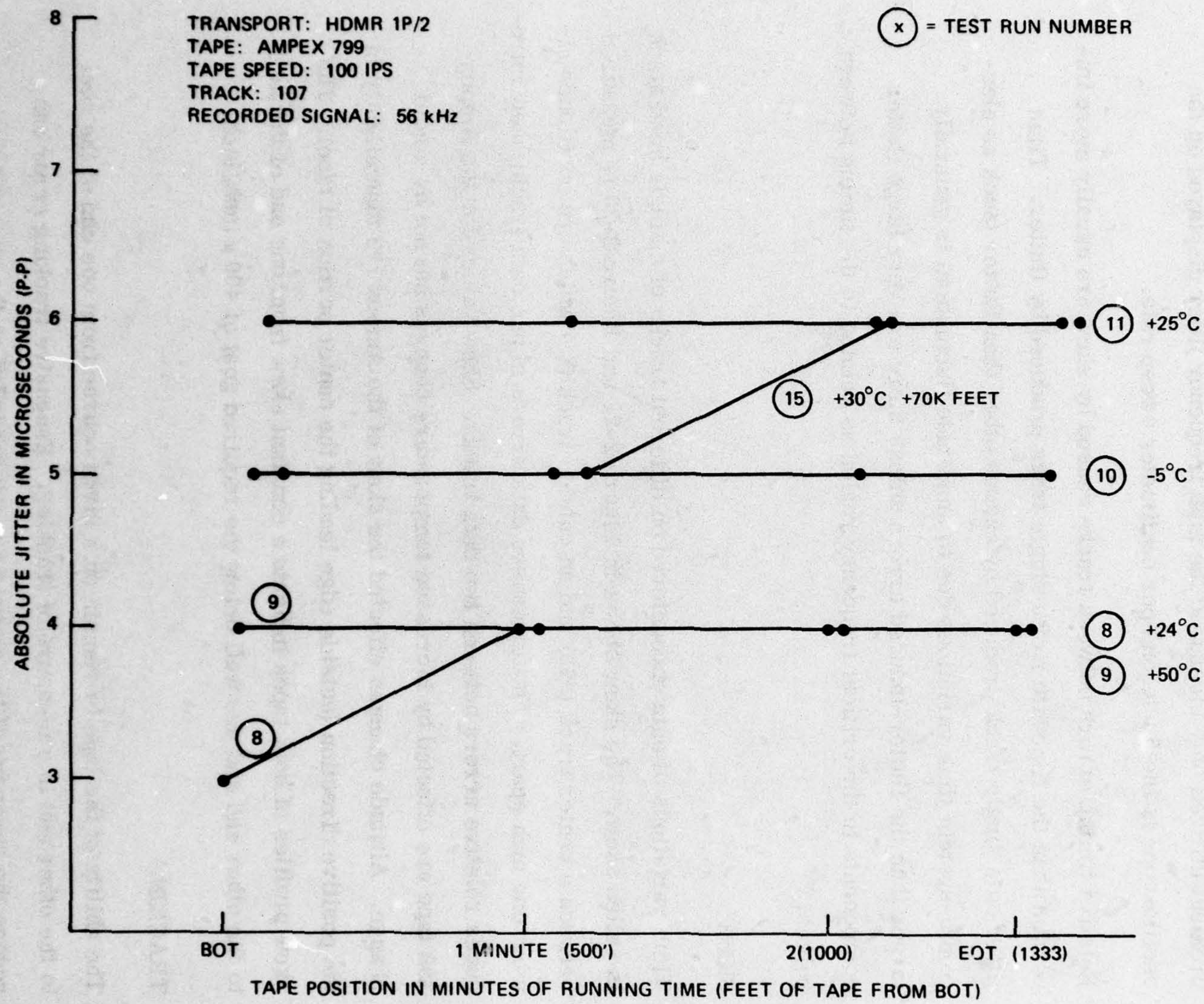


Figure 2-21. Jitter Profile

of one tape indicates a higher value near the center of the data run and are well below the maximum 250 μsecond required goal. The method of measurement utilized only measured the high frequency jitter displayed on the oscilloscope at the 5 μsecond per centimeter sweep rate.

Relative timing errors between tracks caused by skew are usually more important than the time jitter of a single track produced by flutter. Time jitter on a single track produced by causes other than flutter (such as electronic-system time variations due to amplitude fluctuation) is generally larger than the flutter-induced errors unless there are very large flutter components in the critical frequency region as related to the timing between pulses.

2.6.4 SKEW

Time variations of data encountered on different tracks of a single head stack is called skew. The skew shown in Figure 2-22 and Figure 2-23 is measured between a center track (#69) and an outside track (#5) which are positioned almost one inch apart. Flutter causes data errors in one data track; skew introduces relative errors between two data tracks. Skew values for the Ampex 799 tape are effected by increased temperature changes but not by a cold change. Altitude changes effected the skew of the Ampex 799 tape slightly in the positive direction (outside edge leading the center portion of tape). The skew profiles of both tapes indicate a constant skew from one end of the tape to the other end and are well below the required goal of 400 μ inch/inch.

2.6.5 TRACKING

The ability of the tape to remain on a given course from one end of the reel to the other end is a measure of tracking. Excessive tracking error can reduce the recovery of the magnetic track recorded on the tape and thus reduce the signal output, thus diminishing the S/N. It can also cause variations

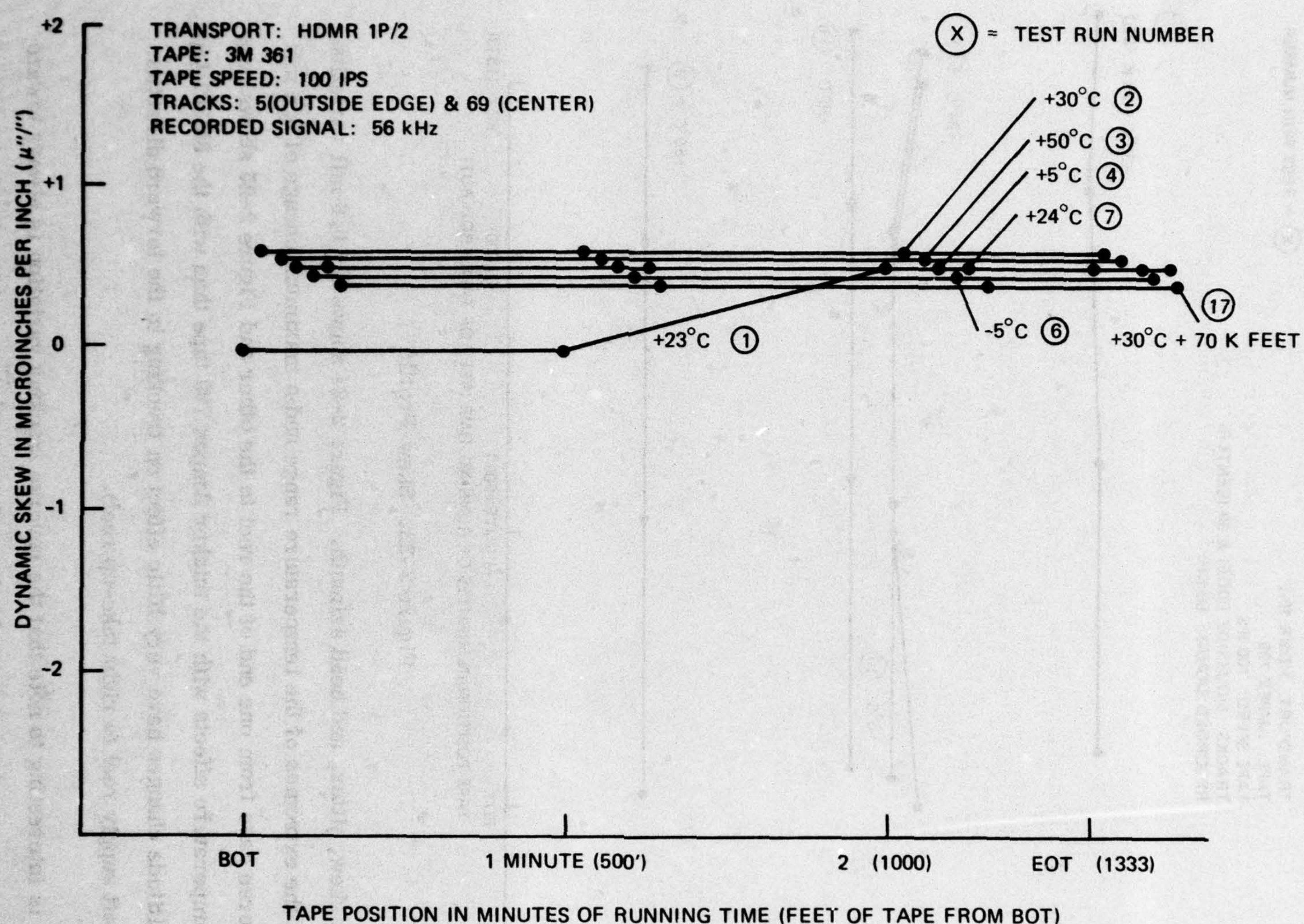


Figure 2-22. Skew Profile

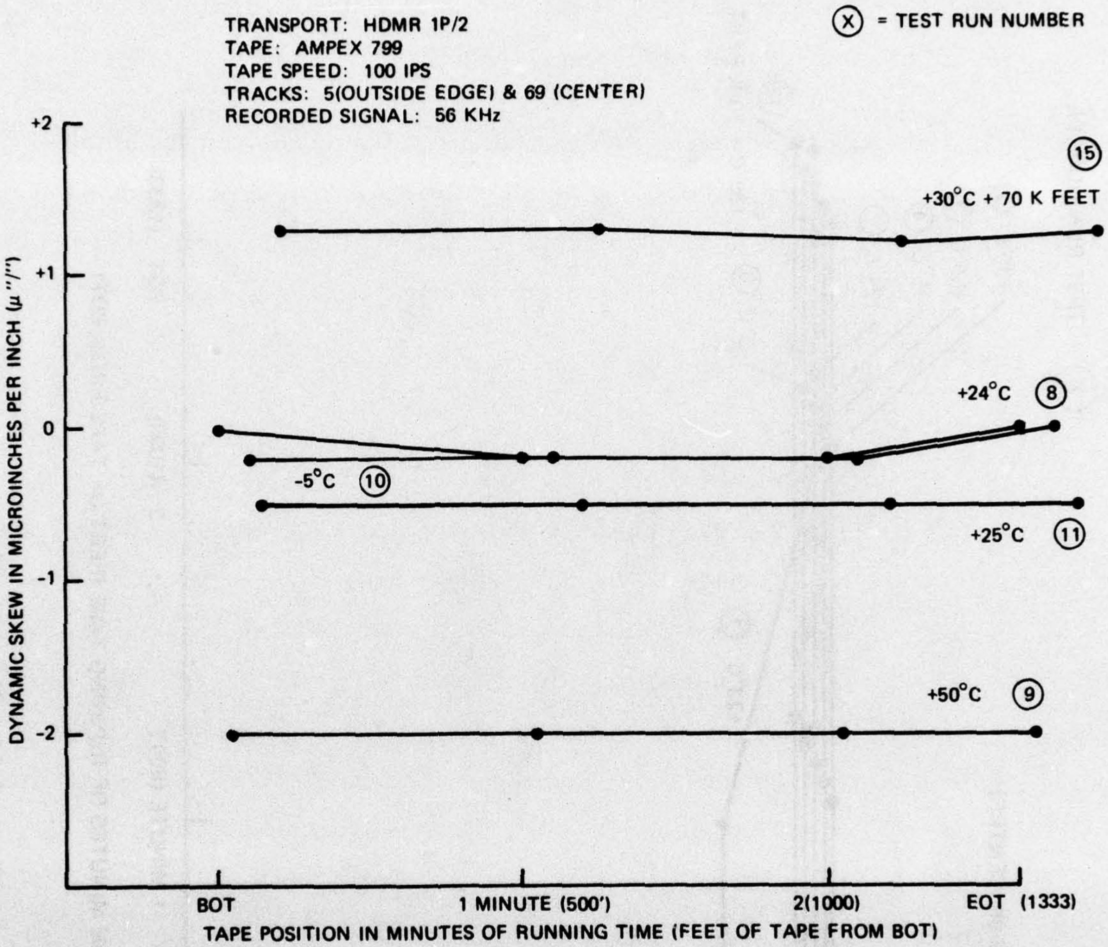


Figure 2-23. Skew Profile

in skew, jitter, and head azimuth. Figure 2-24 shows a ± 0.6 mil variation at the extremes of the temperature range and a maximum change of 0.6 mil worse case from one end of the reel to the other and Figure 2-25 shows less temperature effects with the thicker Ampex 799 tape than with the 3M361 tape. Altitude changes have very little effect on tracking in the forward direction (left supply reel to right take-up reel).

It is interesting to note that the reverse tracking variation is always toward the transport baseplate and only as the tape is approaching the Beginning of Tape (BOT). This variation is 4.8 mils at sea level, 0.3 mil at 70K feet

(0.65 PSIA) altitude, 0.6 mil at 45K feet (2.14 PSIA), 3.6 mils at 20K feet (6.8 PSIA) and 4.8 mils at 6K feet (12 PSIA).

The tracking profiles show maximum error in the middle and end of the tape in the forward direction for the 3M361 tape. The tracking error for the Ampex 799 tape is a maximum of 0.6 mil at the 2-minute (1000 feet from BOT) position. The maximum total error of 1.2 mil is below the 3.0 mils required goal.

2.6.6 SIGNAL TO NOISE

The signal to noise ratio variations from +50°C to -5°C decreased a total of 0.4 db (from 28.2 to 27.8 db) for a 100 u inch recorded signal on 3M361 tape. The recording was made at +24°C and played back at the various test temperatures. Correspondingly, the S/N decreased a total of 1.2 db (from 25.2 to 24.0 db) for a 100 u inch recorded signal on Ampex 799 tape. The tape and system noise remained relatively constant during all these runs; it was the signal level that changed and thus changed the S/N. The altitude environment of +30°C and 70,000 feet improved the signal level 0.5 db on 3M361 and 0.7 db on Ampex 799 tape. An interesting phenomenon occurred during the altitude tests in that the reverse signal level from both tapes was much improved over the reverse signal at sea level. On 3M361 tape the altitude reverse signal was only 1.5 db below the forward direction and at sea level the same recorded signal yielded a reverse signal 10.5 db below the forward direction. The corresponding data for Ampex 799 tape is 2.4 db at altitude and 15 db at sea level. The improvement in reverse performance is due to the lack of air molecules that are normally pumped between the tape and the head by the motion of the tape at normal air pressures. The loss of this air film eliminates the head/tape separation which normally reduces tape and head wear.

A previous study analyzed the S/N characteristics of eight various tapes at various error rates and are plotted in Figure 2-17. The 3M361 tape yielded the highest S/N for the highest BER. The Ampex 799 was next to the worst in this regard.

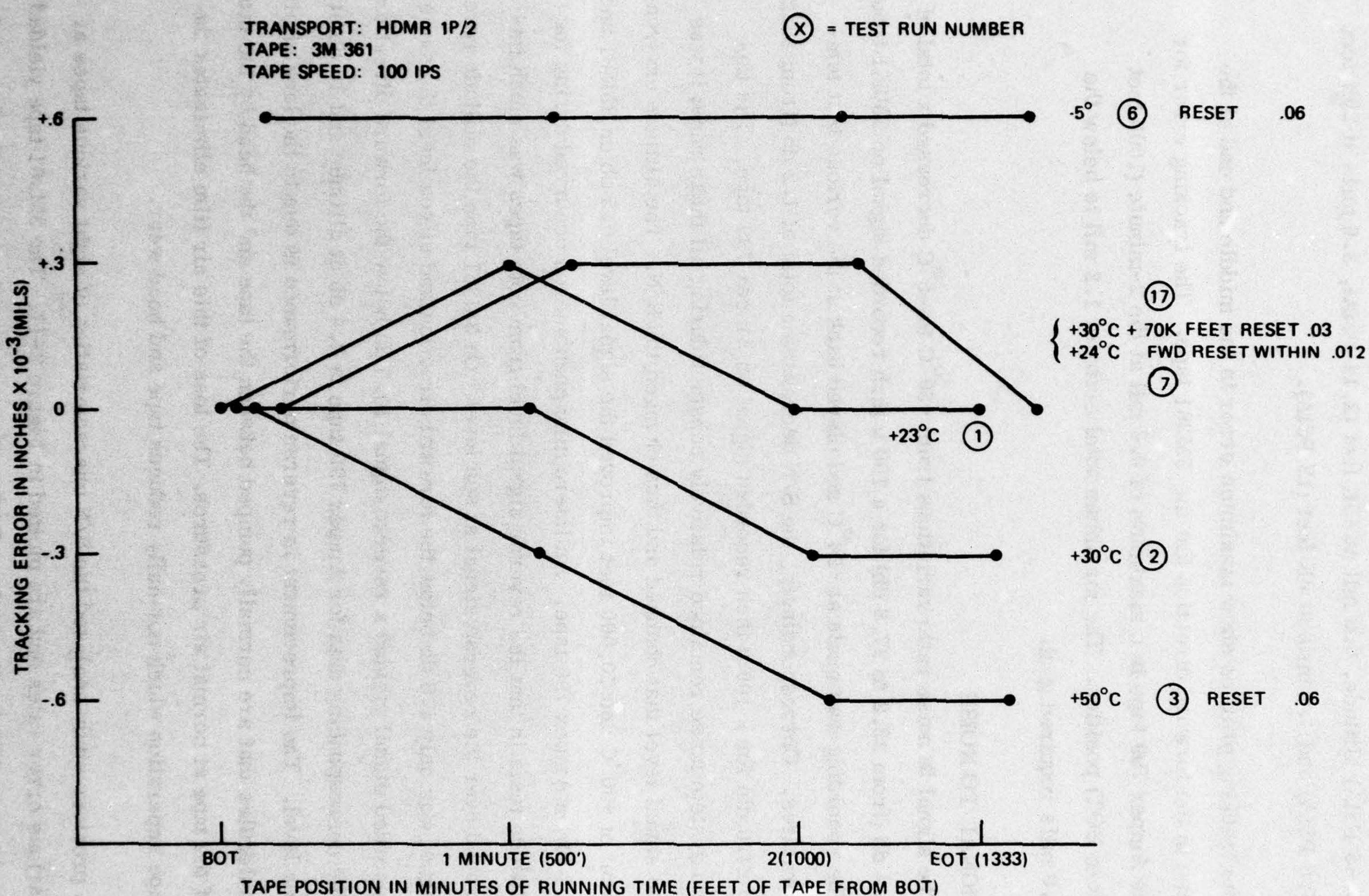


Figure 2-24. Tracking Profile

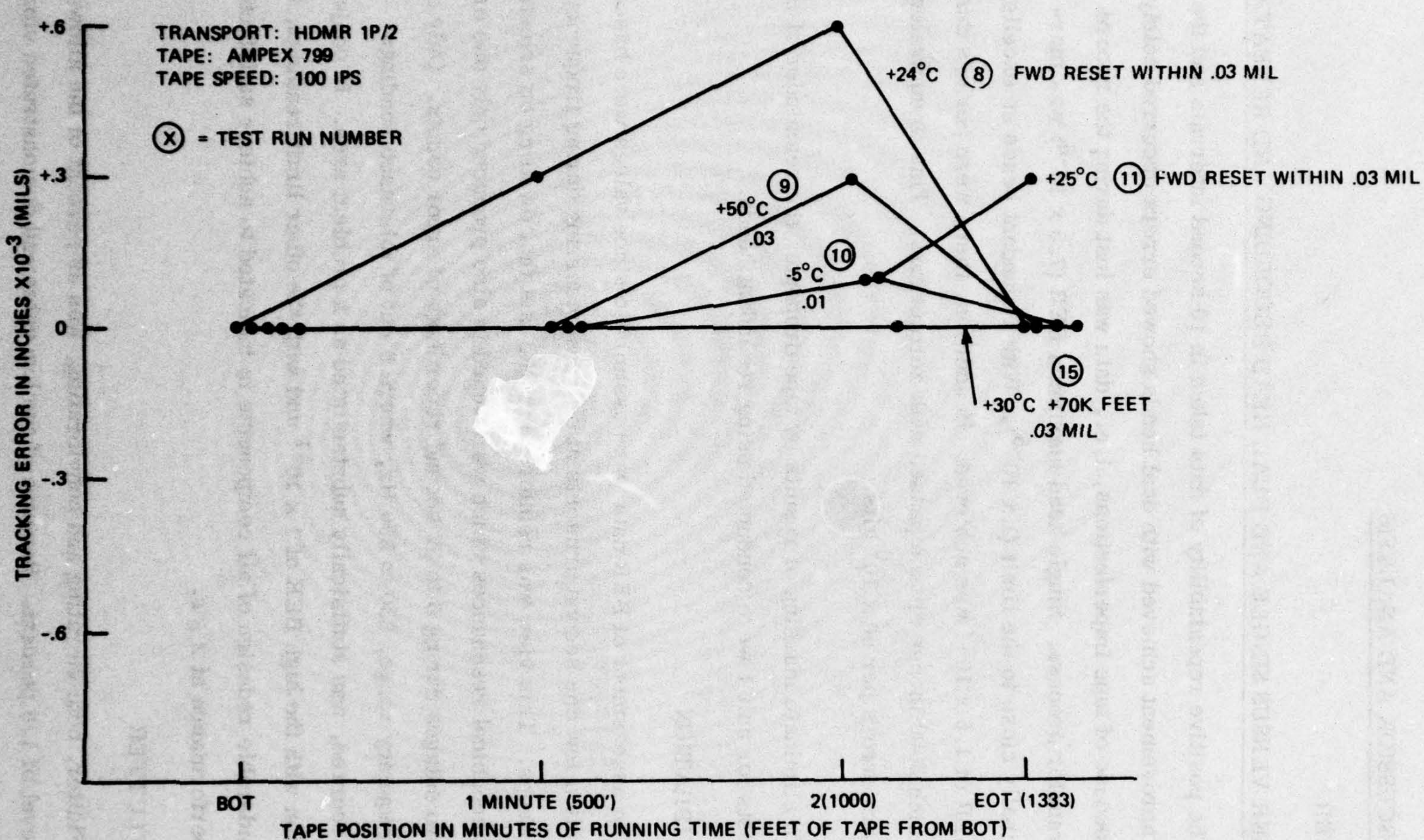


Figure 2-25. Tracking Profile

2.7 UNIT 1 DISCUSSION AND ANALYSIS

2.7.1 BER

BER VERSUS SINGLE AND DUAL HEAD RECORDING AND REPEATABILITY

The positive repeatability of data taken in 10 second intervals and the improvement achieved with dual heads showed errors occurred solely because of tape imperfections, i.e., data was lost during the record transfer process. Single head maximum BER (7.5×10^{-5}) was marginally close to the limit (1×10^{-5}). With redundant heads an excellent BER of 1.6×10^{-6} was achieved. In addition, there were periods during which 3000 inches of tape passed with zero errors. This is equivalent to zero errors per 60×10^{6} bits.

To eliminate masking of results by tape dropouts, the remainder of BER tests for unit 1 were conducted using redundant heads.

2.7.2 VIBRATION

The assessment of BER data was pessimistic since values were based on only a few one second printouts at outages occurring during frequency sweeps. This view was reinforced by the fact that dwelling on selected mechanical resonances which were tuned in also produced only one or two outages during 6 to 37 second recordings of error counts. Only one frequency range, 330 to 390 Hz, where 6 out of tolerance readings occurred, was statisically substantiated as a problem area. In conjunction with the high BER of 1×10^{-1} and with the other limit readings, considerable redesign of all components is indicated to achieve satisfactory performance at 2 g's.

2.7.3 FLUTTER

Flutter, both vibrating and nonvibrating, was 39 percent of the allowable level of 1.0 percent. Because of the low value and demonstrated vibration

stability of this parameter, it should remain well within limits of the full 2 g vibration level even without considering changes that may be made to correct other problems.

2.7.4 JITTER

Nonvibrating jitter was 4 percent of that allowed. Vibrating jitter was not measured. Because of the excellent jitter characteristic of this machine it is anticipated the 2 g vibration condition would not exceed the limit of jitter since the limit is 25 times this amount measured above.

2.7.5 SKEW

With the 0.5 g vibration the skew increased beyond the limit and was in excess of 23 times over the nonvibrating skew value at many frequencies. These frequencies included resonances of every element checked for acceleration response including the deck. The indications are that total redesign is required to achieve satisfactory skew at the 2 g vibration level.

2.7.6 TRACKING

Contoured guide rollers were expected to affect some degree of positive restoring action to correct any lateral tape displacement, comparable to the action of a crowned pulley. In assessing these results it seemed reasonable to assign the greatest weight to DC error, since AC values probably involve some tape head vibratory phenomena. Comparative values of straight roller and contour roller A were close enough to be at the level of experimental error and repeatability. A qualitative judgement is that there may be a small improvement factor with use of contour roller A. Contour roller B showed significant increase in DC tracking error and was eliminated from consideration because track width of the

HDMR systems are nominally about 7 to 10 mils and a tracking error of over 3 mils is unacceptable.

The increase in operating temperature to 35°C was sustained without exceeding the 3 mils tracking error with straight and type A rollers. The slight increase in readings do not warrant a change in design and additional tests at increased temperature are indicated.

The effect of increased temperature was an increase in DC tracking error of all three roller types. Some straight and type A rollers reached the 3 mil limit of acceptability.

2.7.7 SIGNAL TO NOISE RATIO

The deterioration in tape to head contact occurring during some resonances indicated tape tension was marginal under certain conditions. Notably, it became unacceptable at the full 2g level.

A servomotor driven capstan system would be a means of providing the required tape tension and maintaining it constant throughout the entire length of tape.

2.7.8 MECHANICAL

We are most interested in displacement of transport elements, since displacement directly affects performance. Displacements noted are for the 0.5g input used in this survey. A high density recorder which must perform during vibration conditions will have to be mounted via a shock mount system. In accordance with Military Standard requirements, it should also perform at a 2.0g vibration level without shock supports. At 2 g's displacements to be expected in this transport would be four times those calculated in Tables 2.10, 2.11, and 2.12.

Elements most in need of stiffening are the guide rollers in the X axis and the capstan housing in the Z axis. Three to four mils movement at 0.5g become 12 mils at 2. g's, much more movement than is tolerable. Irregular tape stack on the reel during resonance of the guide roller is evidence of tape movement that occurs under those conditions.

The apparent deck resonances at 360, 575, and 670 Hz artifically increased vibration levels at these frequencies. Responses at 575 Hz were primarily deck resonance with the amplification being 6. Dividing component responses by 6 would essentially eliminate problems at this frequency. Apparent deck resonance could probably be eliminated for test purposes by controlling vibration input from a deck mounted accelerometer instead of a low point on the side rail.

The range of maximum component g levels and double amplitude displacements ranged from 15 g to 3 g and 1.5 mils to 0.28 mils. Table 2-23 and 2-24 list problem areas and components with their responses in two ways in an attempt to relate high responding components with problem areas. There were many resonances and all components were resonant at some problem frequency, and often simultaneously, no one component was indicated as the primary cause.

Counting first and second place in the number of maximum response at problem areas (Table 2.14), the capstan had 5 places, the head and motor 4, the sensor 3, and the roller 1.

At this stage the relationship between problems and response is difficult to see because of multiple and varied conditions. This includes resonant and g level displacement as low as 3g's and tenths of mils. The one common manifistation is that one or more component or deck resonance usually exist with operational problems.

Table 2.14 shows true component responses for Y axis when component resonances are normalized for deck resonance. This shows the importance of a rigid deck in eliminating component resonances.

TABLE 2-23. COMPONENTS LISTED IN ORDER OF DECREASING RESPONSE PROBLEM AREAS OF UNIT 1

Frequency Hz	BER	Flutter %	Jitter	Skew μ "/"	Order of Decreasing Response of Components Highest →					Lowest
360	XX 2x10^{-3}	0.1	Not Measured During Vibration	XX ≥700	15/.0026" Roller	10/.0015" Sensor	5.2/.0007" Capstan	4.2/.00057" Head	2.2/.00038" Motor	1.4/.00024" Deck
450				XX ≥700	4/.00043 Sensor					
527	2x10^{-3}									
575	XX 6x10^{-3}	0.09			8.4/.00052 Capstan	6/.00041 Motor	5.4/.00031 Head	4/.00025 Sensor	3/.00019 Deck	
617				XX ≥700	3/.00015 Capstan					
670	XXX 2x10^{-2}			X	5/.00021 Head	4.5/.00019 Motor	4/.00018 Capstan	1.7/.00008 Deck	1.3/.00006 Sensor	
723		0.2			10/.00034 Capstan	1.2/.00005 Roller				
780	X 2x10^{-4}									
835	X 2x10^{-4}			XX ≥700	9/.00025 Motor	5/.00001 Capstan	3/.00008 Head	1.1/.00003 Roller		
970	X 6x10^{-4}	0.06			4.8/.00010 Head					
1360	X 5x10^{-4}				4.8/.00005 Motor	3.2/.00005 Head	2.7/.00002 Capstan			
1710	X 4x10^{-4}			XX ≥700	10.5/.00007 Capstan	0.9/.00001 Sensor				
1940	1.6x10^{-4}			XX ≥700	5.8/.00003 Capstan	3.4/.00002 Head	2.9/.00001 Sensor			

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TABLE 2-24. COMPONENTS LISTED IN ORDER OF MAXIMUM RESPONSE

	X-Axis		Z-Axis		Y-Axis		*Y-Axis True Component Responses	
Max. 1st & 2nd Response at Problem f	Max. Double Amplitude"	Max. G	Max. Double Amplitude"	Max. G	Max. Double Amplitude"	Max. G	Max. Double Amplitude"	Max. G
Capstan 5	Roller .0026	Roller 15.0	Capstan .0039	Capstan 44.0	Motor .00195	Roller 9.5	Capstan .00069	Capstan 3.5
Head/ Motor 4	Motor .00155	Capstan 10.6	Roller .00115	Head 12.8	Capstan .00192	Motor 7.8	Roller .00008	Roller 3.3
Sensor	Sensor .00151	Sensor 10.0	Head .00076	Roller 9.7	Sensor .00169	Head 7.4	Motor .00007	Motor 3.2
Roller 1	Capstan .00135	Motor 9.0	Sensor .00072	Sensor 8.2	Roller .00130	Capstan 6.3	Sensor .00004	Head 2
	Head .00103	Head 5.4	Motor .00049	Motor 4.4	Head .00119	Deck 6.0	Head .00002	Sensor 1.3
	Deck .00027	Deck 3.0	Deck .00019	Deck 2.4	Deck .00110	Sensor 5.2		

*Responses Corrected for Deck Transmissibility

2.8 UNIT 2 DISCUSSION AND ANALYSIS

2.8.1 BER

Single head nonvibrating BER in this unit was higher than in unit 1 and therefore above the limit because the 10,000 foot tape used had high dropouts. The high dropout rate was due to the type of tape (3M971) used and because it had not been burnished by a tape run-in step.

At the time these tests were performed, equipment required for a dual head test set up was not available, therefore it was necessary to continue with vibration tests using single head and reference results to $4x10^{-4}$ non vibrating BER. Except for 3 resonant frequencies, the BER did not increase above the nonvibrating BER.

High BER readings were associated with component resonances and higher tracking errors although these were within the acceptable 3 mil limit. The upper guide rollers and tape loop sensor were clearly the maximum response components. Their values at the critical frequencies are given in Table 2-25. Further discussion of offending components are given under tracking and mechanical sections.

TABLE 2-25. UPPER GUIDE ROLLER AND TAPE LOOP SENSOR RESPONSES FOR BER CRITICAL FREQUENCIES

Frequency	Upper Guide Roller		Tape Loop Sensor		Deck
	Rail Control	Deck Control	Rail Control	Deck Control	Rail Control
(Hz)	(g/D.A.")	(g/D.A.")	(g/D.A.")	(g/D.A.")	(g/D.A.")
230	6.4/0.00236	1.2/0.00048	4.0/0.00148	1.4/0.00052	1.5/0.00055
350	17./0.00263	2.8/0.00045	13/0.00233	5.8/0.00092	1.3/0.00022
440	17/0.00180	34/0.00359	1.7/0.00017	3.1/0.00031	.4/0.00004

g/D. A." = Acceleration (G level)/Displacement Amplitude in Inches (Peak to Peak)

The rail control columns give responses attained during the BER test. These component responses were strongly influenced by transport deck/rail resonances as shown by levels of component response when input was controlled at the deck. With these reduced levels an improved BER would result except at 440 Hz where it would deterriorate further. These results indicate the desirability of a stiffer deck for further tests to determine whether all levels would decrease by eliminating antiresonance frequencies.

2.8.2 FLUTTER

Flutter values were extremely low. Maximum vibrating discrete flutter value (0.16 percent) occurred at 728 Hz which coincides with a high capstan response of 9 g's, The total effect of vibration was to increase percent flutter from 0.03 percent to 0.21 percent.

2.8.3 JITTER

The 8 μsec jitter was well within the 250 μsec allowable jitter. No measurable increase in jitter occurred from nonvibrating to vibrating environment.

2.8.4 SKEW

Skew values did not exceed the 400μ inches/inch limit in either non vibrating or vibrating environments.

Certain mechanical resonances caused some transport elements to vibrate at 10-20g levels. At some of these peaks, dynamic skew increased from 100×10^{-6} inches/inch to about 300.

2.8.5 TRACKING

Tracking errors during the 0.5g vibration were small throughout the major portion of the test range. At certain frequencies, between 100 and 1100 Hz, they approached the full allowable limit and once it was exceeded. Increases in tracking were accompanied by high resonant response of one or more components. In order of greatest response levels these were upper guide rollers,

tape loop sensor, head, capstan and deck. The affect of the deck was shown by greatly reduced responses in components when input was controlled at the deck (X axis). In addition all low frequency responses followed the deck response in the Y direction.

Specific vibration levels above which at tracking errors will occur, cannot be established from this data. For instance, in the X axis, a 1.5 mil tracking error occurred with 12 g and 3.5 mils maximum component response (at 275 Hz) while twice the error occurred at 6.4 g and 2.4 mils maximum response (at 230 Hz). This was for the same component (upper guide roller) and frequencies were not widely separated. Only quantitative estimate can be made from this data. It appears maximum component displacement should not exceed 2 mils and 6 g's.

Although 3 mils tracking error was the calculated allowable for satisfactory performance, out of limits BER occurred at this level and also at 2 mils.

2.8.6 SIGNAL TO NOISE RATIO

The constant level observed in BER signal data indicated tape to head contact was satisfactorly maintained with no deterioration under any conditions.

2.8.7 MECHANICAL

Each component except lower guide rollers, which had been redesigned as a result of experience gained from unit 1 testing, had high g level and peak to peak displacements in excess of 1 mil. Responses in X and Z axis were highest. In the X axis test, when the g level was controlled at the deck, component responses were generally considerably reduced and performance would be correspondingly improved. However, at 450 Hz, response of the upper guide roller doubled. This could have been related to an antiresonant response of the deck at that frequency, which would not occur in a stiff deck, or it could be a true resonance of the upper guide roller. The transport components causing the majority of the problems were the upper guide roller, tape loop

sensor and capstan housing. Design improvements can, and in one case, already have been implemented to raise their natural frequencies. These techniques include using lighter weight materials while maintaining structural stiffness.

The upper guide roller was supported on a pedestal mounted to the deck. This resulted in it being susceptible to vibration deflections. Corrections could be made to this design by utilizing a stiffer pedestal or bringing the deck up to the base elevation of the guide roller.

The tape loop sensor also presented problems at lower frequencies. It was made entirely of stainless steel for convenience and expediency in this breadboard system. Its natural frequency could be altered with the use of larger cross sections and lighter materials (magnesium or aluminum) with stainless steel inserts at precision bearing locations. Main roller and support shafts should also be stiffened by simply using larger diameters.

The capstan housing reached 32 g's and 5 mils in the Z axis. A redesigned capstan has already been implemented in the next co-planar unit. It has the single stiff post support exactly like the guide rollers. It is important to note that the lower guide roller never exceeded a 1 mil peak-to-peak displacement in any axis (36 g's maximum in Z axis at 850 Hz); so this component has already been successfully improved. However, a limit tracking error did occur in conjunction with a high head response. The general improvement expected from a stiffer deck may carry these components through the full g level.

In the Y axis, a second control position was not attempted, but since all responses at the low frequency end followed deck vibration, a stiff deck should result in further improvement in this axis. In conjunction with these results it was visually observed that the coaxial reel assembly was moving and also could have been a contributor to deck responsiveness at low frequencies. Upper frequency responses were all low and should cause no problems.

2.9 SUMMARY AND CONCLUSIONS

2.9.1 UNITS 1 AND 2 PERFORMANCE SUMMARY MEASURED AND PROJECTED WORST CASE VALUES FOR TEST SPECIMENS

Table 2-26 presents a summary of measured and projected worst case performance values of the two recorders as tested along with values required to achieve desired airborne performance. The projections are assuming nonlinear displacement with g level on the basis of increased damping and probable nonlinear parameter response.

Both recorders had unsatisfactory BER performance at component resonance frequencies at the 0.5g test level. The projected value, however, is unsatisfactory. Tracking was unsatisfactory at the 0.5g level at component resonances. Tape to head contact had problems in Unit 1 and is projected to be unsatisfactory at 2.0g. Unit 2 tape to head contact was projected to be satisfactory at the 2.0g level. Tape tension levels used are provided. Component displacement and g levels were with values reaching 8 mils and 90 g's projected for Unit 1 and 10 mils and 100 g's projected for Unit 2.

2.9.2 PERFORMANCE SUMMARY UNDER TEST CONDITIONS

Using burnished tape on unit 1 resulted in a nonvibrating single head maximum BER of 7.5×10^{-5}.

Two heads in parallel resulted in BER of 2×10^{-6}, which was much better than required. After one vibration sweep, the BER increased to 1.5×10^{-5} and the cause for this was not determined. This reduced BER is very close to the required 1×10^{-5} rate.

Unit 2 with one head and unburnished 3M 971 tape, had a nonvibrating BER of 4×10^{-4} which was in excess of requirements.[1] In the X axis the BER increased at worst case resonances by a factor 10^3 on both units. A direct relationship between g/displacement was not apparent but a 3.0 g and less than 0.001 inch peak to peak displacement appears a desirable general limit for component vibration. Redesign should use this number as a goal.

Tracking was marginally out of limits in unit 1 and in unit 2 it was within limits in the X and Y axes. In the Z axis, however, unit 2 tracking was considerably out of limits (design improvements necessary.)

Jitter and flutter were well within requirements on both units. Tape to head contact was satisfactory with the servocontrolled motors on unit 2 which maintains tape tension at two pounds.

The vibration input was to the transport components and therefore their response was strongly influenced by deck response and vibration control measuring methods, particularly in the Y axis. The control method was corrected on unit 2 during the Y axis test.

Since most of the actual performance parameters of unit 2 were within limits at test level and since levels that were projected to be out were out by a manageable amount, it is recommended unit 1 be abandoned and unit 2 have design improvements made and tested.

2.9.3 RECOMMENDATIONS FOR UNIT 2 DESIGN CHANGES AND FUTURE VIBRATION TESTING

(1) <u>DESIGN CHANGES</u>

(a) Use inplane tape path

(b) Increase stiffness and mounting methods of components (most critical items are capstan, guide rollers and tape sensors)

(c) Assure that resonances of components do not coincide with each or with deck resonances.

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[1] Limited by available vendor furnished electronics at time of test.

(d) Use a very stiff deck with 700 Hz or higher natural frequency as a goal, to prevent deck induced and deck transmitted component resonances.

(2) <u>TEST RECOMMENDATIONS</u>

(a) Select burnished tape and use run in with tape head.

(b) Use redundant heads if necessary to achieve nonvibrating BER below requirements under vibration.

(c) Mount transport rigidly to a high resonance fixture and use different fixturing in each direction if required.

(d) Mount control accelerometer to fixture at deck input point or on deck if deck is not representative of transport deck.

(e) Locate frequencies of poor performance and vary input g level to determine breakdown threshold to establish the offending element and what degree of modification, if any, is required.

(f) Establish ranges of frequencies between component resonances where satisfactory performance at the required 2g input level can be maintained.

(g) Perform vibration tests in all three axes.

(h) Perform operational tests at required temperatures and altitudes.

(3) <u>CONCLUSIONS</u>

An airborne HDMR tape transport which must operate under vibration conditions is quite feasible with certain design changes as shown by these tests. All tracking, skew and BER problem areas are related to resonances of transport elements which can either be eliminated or adequately stiffened in a final design.

TABLE 2-26 PERFORMANCE SUMMARY UNIT NO. 1 & UNIT NO. 2

Measured & Projected Worst Case Values for "as-is" Test Specimen

Transport Parameter	Required	Unit No. 1			Unit No. 2		
		Data		Projected	Data		Projected
		Non Vib.	0.5 g X Axis	2 g t	Non Vib.	0.5 g X Axis	2 g t
BER/channel	* 10^{-5}	* 2×10^{-6}	* 2×10^{-2}	X	** 4×10^{-4}	** 1×10^{-1}	X
Flutter (Cumulative) %	1.0	0.28	0.39	0.8	0.03	0.21	0.4
Jitter (μs p-p)	250	10	NR	NR	8	NR	NR
Skew (μin/in)	400	30	≥700	1400	100	300	600
Tracking (mils)	3	2	≈ 4	8	2	3 (7 in Z)	7
" " at 35°C		3	--	--	--	--	--
Tape/Head Contact	good	good	some *problem*	X	good	good	√
Tape Tension (lb)	1.6 to 2.4	1.1 to 1.75	NR	NR	2	NR	NR
Physical Elements Displacement (mils p-p)		NA	2.6 (3.9 Z Axis)	5 8	NA	3 (4.9 Z Axis)	6 10
Acceleration - g		NA	15.0 (44.0 Z Axis)	30 90	NA	17.0 (47.0 Z Axis)	35 100

* Redundant tracks or with EDAC

**Single track

t Extrapolated to MIL-E-5400 Vib. Level

NR Not Required

NA Not Applicable

X INADEQUATE

√ ADEQUATE

-- NO DATA

Projected data assumes at least 2:1 damping $(\frac{2g}{.5g} \times \frac{1}{2} = \times 2)$

3.0 EVALUATION OF TAPES AND HEADS

3.1 SPECIFYING PARAMETERS

Basic performance parameters may be independently specified for both the tape and heads. Parameters usually specified independently include:

Tapes

- Dropout Incidence and Size
- Handling on Transport
- Effect on Head Wear
- Life
- Signal Output

Heads

- Track Density
- Required Isolation
- Wear Characteristics
- Tape Handling

When total system requirements are considered the interface between the tape and heads (the effect of one on the other or the combined effects) becomes the most critical item.

3.2 TAPE TEST DATA

3.2.1 TYPES EVALUATED

Twelve tape types have been evaluated or partially evaluated for this type of application, as part of various head performance investigations:

3M	Type 900	3M	Type 461
3M	Type MTA 20478	3M	Type 455B
3M	Type 971 (Old)	3M	Type 971 (New)
Dupont	Cr02	3M	361
Memorex	M202 (Cr02)	Ampex 143	
Memorex	716	Ampex 799	

As a result of prior extensive tape testing at RCA, a preliminary determination is that the Memorex 716 or Ampex 143 tape is most suited for use on the HDMR recorder. Parameters important to this selection were: (1) Tape performance; (2) Handling on the Transport; (3) Tape Life and Preparation; and (4) Effect on Head Wear.

3.2.2 TAPE SELECTION CRITERIA

Tape types are evaluated against the following criteria (not necessarily in order of importance):

(1) Output level (S/N)

(2) Record drive requirements

(3) BER

(4) Preparation requirements, e.g., burnishing

(5) Tape life

(6) Head wear/life effects

(7) Transportability characteristics, e.g., guidance, stacking

(8) Contaminant generation, e.g., oxide shedding, mylar shedding

(9) Physical consistency, e.g., hardbanding, coating and backing variations

(10) Repeatability of manufacture

(11) Environmental effects on above characteristics

It is presently expected that Memorex 716 or Ampex 143 tape will be the optimum choice of tape; however, new developments and further evaluation may change that choice. It is highly possible that a new 3M tape of 500 to 700 oersted range may be available, which could provide increased S/N margin for the system and therefore increased BER margin. Greater output signal level is obtained for sine wave recording ($\lambda = 100\,\mu''$) from High Energy tape (3M 455B, 3M 478, Memorex 716, and 3M 971) than from Low Energy tapes (Ampex 143, 3M 361, and Ampex 799). Output signal levels for DM pulse recording ($\lambda/2 = 50\,\mu''$) from Low Energy tapes and, High Energy tapes, are about the same (See Figure 3-1).

Helical scan type of tapes (Ampex 143, 3M 361, 3M 455B, and Memorex 716) generally produce greater output signals, for both sine wave and pulse recording ($\lambda/2 = 50\,\mu''$) and for both High and Low energy tapes, than Instrumentation type of tapes (3M 478, Ampex 799, and 3M 971). (See Figure 3-1).

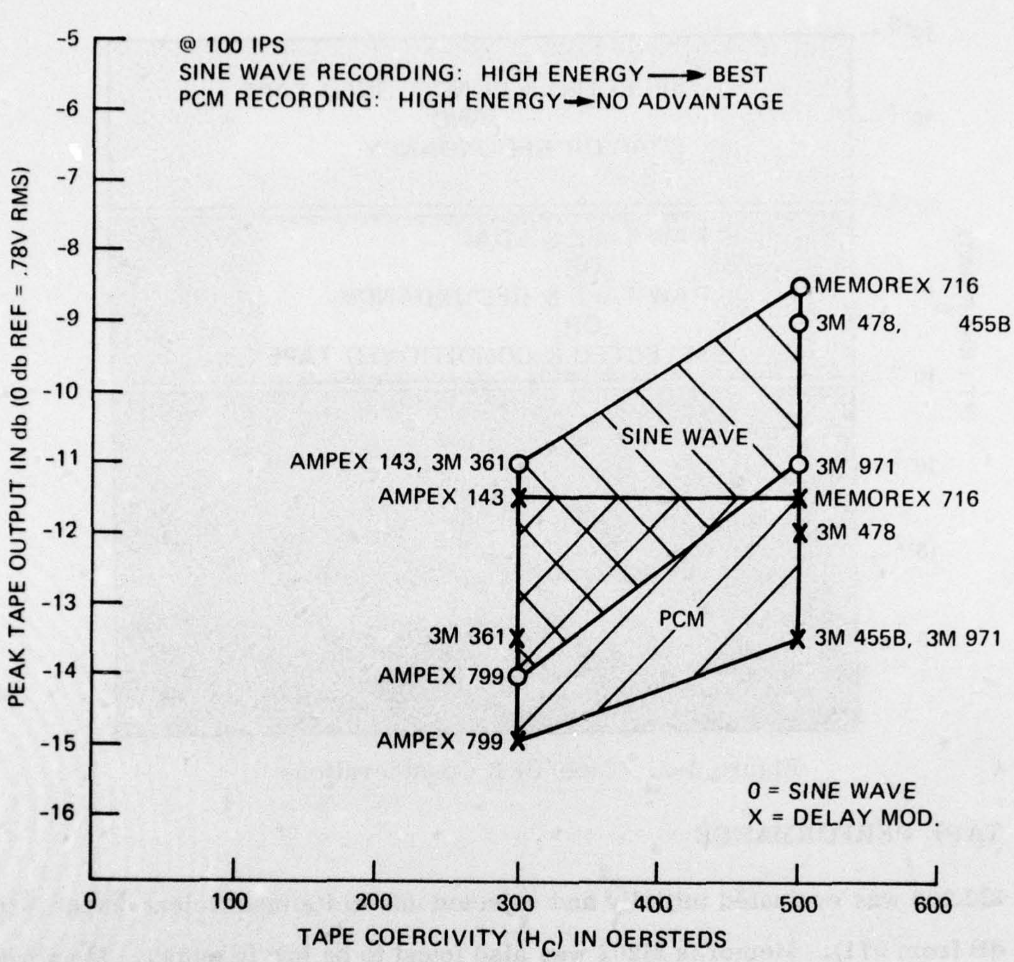


Figure 3-1. Peak Tape Outputs vs Tape Type

More significant than S/N would be development of an improved-surface tape which would drastically reduce the number of "drop-outs" incurred. Figure 3-2 indicates the level of tape conditioning and error correction necessary to improve the BER to a desired level.

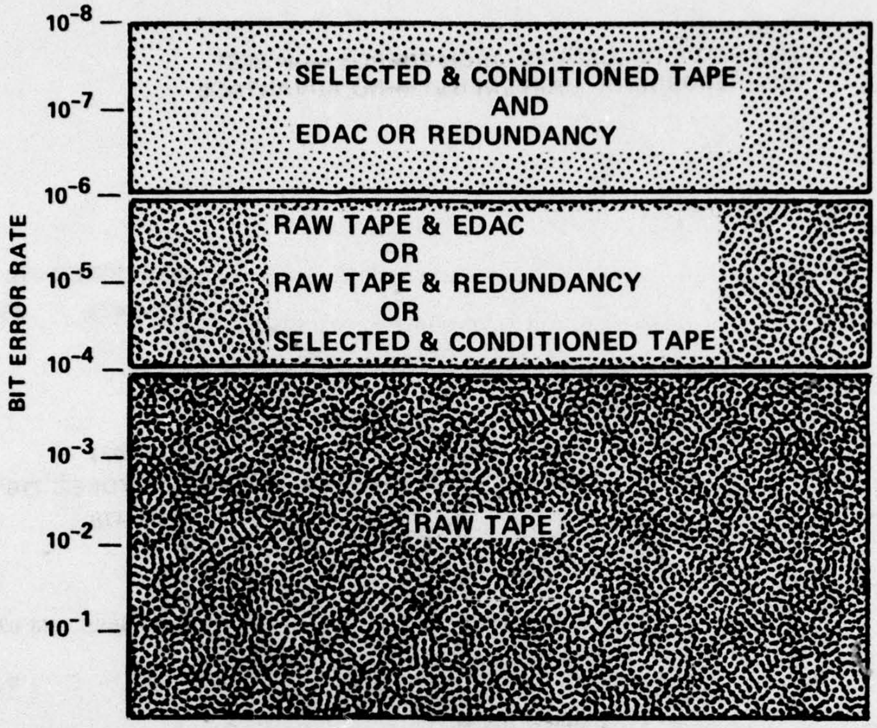


Figure 3-2. Tape/BER Considerations

3.2.3 TAPE PERFORMANCE

3M 900 was evaluated initially and rejected due to its insufficient output (-10 dB from 971). Memorex M202 was also found to be low in output. Memorex 716 CrO_2 (chromium dioxide) tape has the exact same output/performance as both 3M MTS 20478 and Ampex 143. On a purely signal-to-noise (SNR) basis, all three tapes are equivalent.

The characteristics of these specific Memorex, 3M, and Ampex tapes are such that a satisfactory output signal level was produced at reasonable record currents for the system. With 3M MTA 20478 tape, after suitable wear-in (burnishing), a raw bit error rate (BER) of between 1×10^{-5} and 3×10^{-5} was produced at the area packing densities for the feasibility system. With that raw BER, a BER of 5×10^{-7} resulted using the EDAC (error detection and correction) technique for the 14 channel breadboard system implemented in the lab. Extra-

polation to a 160 channel system results in a BER of 10^{-6}. The Dupont CrO_2 produced greater drop out activity for an equivalent burnishing time.

3.2.4 TRANSPORT HANDLING

Memorex 716 and 3M MTA 20478 tapes handled very well on the flangless bread-board transport. The base material and oxide coatings showed few hard-banding (uneven thickness of base material) or coating variations which would affect transportability. Both have the textured backing material; of great benefit in aiding tape stacking and tracking ability and proven beneficial in minimizing tape damage due to debris. The Dupont CrO_2 tape tested had more hardbanding in the base material and did not have the textured backing. The oxide coating appeared consistent. These drawbacks would not in themselves cause this tape to be rejected, for corrections can easily be made in these areas. This tape was not used solely because of the head wear it caused. Its prime benefit to the program was its use as a lapping tape for contouring in the heads. This could be done while monitoring head performance, a feature not available with the lapping tape previously used.

3.2.5 HEAD WEAR DATA

Extensive head wear tests have been conducted at RCA using 3M 900 and Dupont tapes. The average pole face wear on the heads is listed below at 100 inches/second tape speed.

3M 900	0.0×10^{-6} inches/hour
Dupont CrO_2	2.0×10^{-6} inches/hour
3M 971 / 3M MTA 20478	0.4×10^{-6} inches/hour

The above figures given are for burnished tape.

(1) <u>3M 971/MTA 20478</u>

Extremely low wear rates have been experienced for Alfecon II heads on 3M 971/MTA 20478 tape. The low wear is due not only to the toughness

and hardness characteristics of the Alfecon II material and low wear characteristics of the 3M tape, but also to the mechanical design of the head itself. The use of 3M tape results in a very fine and gentle wear characteristic which causes wear at the molecular level.

Head wear rates with 3M 971 tape are difficult to measure accurately with less than 500 hours of closely monitored pole face depth (PFD) wear. Approximate data on head wear accumulated on the head presently being used in the breadboard test equipment has been obtained during the course of the system development. This head has been used extensively in three different transports with various types and samples of tape. In the course of investigating various tapes and equipment parameters, and optimizing head performance, much excessive head wear was accumulated. Ambient conditions were not controlled or monitored. It can be expected, therefore, that this head has experienced higher wear rates than would be expected for a head operating at steady state conditions; Even so, 775 hours of use have been accumulated on this head, and the head is still in use.

(2) 3M 900

On another HDMR transport, a similar head has been operating for over 14 months non-stop, with no head wear, no tape wear, and no change in BER. This test has run over 80,000 passes of tape (1000 ft) or 80 million feet of tape over the head.

(3) DUPONT CrO_2

Chromium dioxide coated tape contains magnetic particles which are longer and thinner than Gamma ferric and cause gouging of head material. This shows up as chips removed from edges of gaps and Alfecon II grain boundaries. Even though Alfecon II is extremely tough and this effect causes no shattering of material, it still digs up the head surface. It has been noted that even after 1500 tape passes the Dupont CrO_2 tape still exhibits gouging and associated high head wear characteristics.

3.2.6 TAPE WEAR

Previous tape testing has not shown any tape used to exhibit end of life characteristics. In all cases tape performance is improved with use except when abused or overstressed.

If a tape has been conditioned and is operating in final configuration on an adjusted transport with a contoured head in a clean environment, there is little wear involved and very little cause for damage. Based on observations and measurements from previous programs, many thousands of passes are achievable without any tape wear-out problems.

3.3 HEAD/TAPE INTERFACE DATA

As stated in the previous paragraphs, neither tape failure nor head failure are limiting items. A much more likely failure mechanism is the head/tape interface area.

3.3.1 TAPE DROP OUTS

Observations of 3M MTA 20478 tape shows virtually no voids in the oxide coating greater than 3 mils in diameter. Although such voids will cause some loss in signal level, they will not seriously affect the BER due to the SNR margin being better than 6 db (7 mil track). The ultimate dropout is caused by either tape oxide roughness or particulate debris on the tape or head.

3.3.2 HEAD TO TAPE CONTACT

The well known loss factor for separation of 54 db/λ is one of the constants that must be tolerated when using any tape, it results in severe loss in signal level as the BPI and/or tape speed is increased. The faster the tape is moved across the head the more tendency

there is for skipping or flying due to mechanical disturbance and aerodynamics in the transport. For these reasons, the longest wavelength and slowest tape speed are best.

An actual separation of five microinches has been measured on this system using transverse/longitudinal techniques. This figure calculates to produce a loss at 21,333 BPI (107 microinches) of 5/107 x 54 or 2.5/db of reproduce signal loss. Similar problems of a slightly different nature exist in record, causing variations in record transition location as well as in record magnetization levels. If this figure (54 db/λ) were applied equally to record and reproduce, vs. BPI, the loss becomes more noticeable.

Separation	BPI	Reproduce Loss	Record Loss	Total Loss
4μ inch	21,333	2.5 db	2.5 db	5.0 db
4μ inch	25,000	3.4 db	3.4 db	6.8 db
4μ inch	33,000	4.5 db	4.5 db	9.0 db

3.3.3 SNR (Signal to Noise Ratio)

The reproduce SNR of the head has been measured using sinewaves at various frequencies in the band of interest. Initially this performance criteria was used extensively for evaluating relative head performance. Of late, the head outputs have only been evaluated for actual delay modulation record-equalized output levels. The SNR data is, however, pertinent for evaluating system performance during the design phase. Figure 3-3 shows a plot of typical SNR performance.

3.4 TAPE PREPARATION BY THE MANUFACTURER

All new (virgin) tape samples tested prior to 1975 exhibited relatively poor BER performance due to random protuberances in the oxide coating. These irregularities in the tape

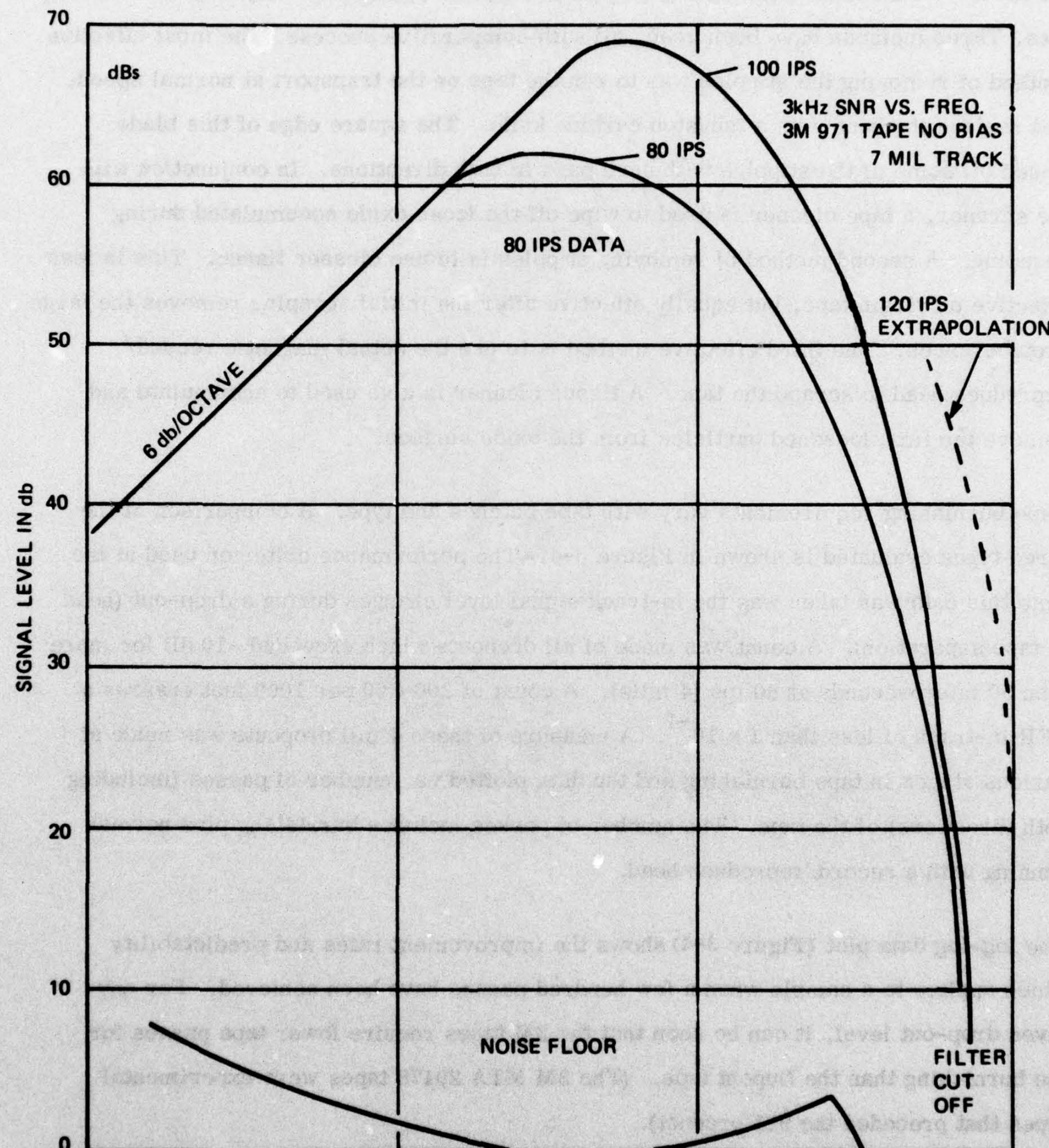


Figure 3-3. Expected Head SNR

surface appear as tall thin mesas which effect a head-tape separation when they pass over the head. We found it advantageous to run in a tape to remove the majority of these stipples. Three methods have been used, all with comparative success. The most effective method of removing the stipples was to run the tape on the transport at normal speed, and replace the head with a tungsten carbide knife. The square edge of this blade sliced off some of the stipples with each pass in both directions. In conjunction with the scraper, a tape cleaner is used to wipe off the loose oxide accumulated during scraping. A second method of removing stipples is to use cleaner tissue. This is less effective on virgin tape, but equally effective after the initial scraping removes the large protuberances. The third effective method is to use the actual magnetic record/reproduce head to scrape the tape. A tissue cleaner is also used to accumulate and remove the final loosened particles from the oxide surface.

Tape burnishing requirements vary with tape batches and type. A comparison of the three types evaluated is shown in Figure 3-4. The performance criterion used at the time this data was taken was the in-track signal level changes during a drop-out (head to tape separation). A count was made of all dropouts which exceeded -10 dB for more than 50 microseconds at 80 ips (4 mils). A count of 200-300 per 1000 feet ensures a BER in-track of less than 1×10^{-4}. A measure of these 4 mil dropouts was made at various stages in tape burnishing and the data plotted vs. number of passes (including both directions) of the tape. The number of passes includes burnishing plus normal running with a record/reproduce head.

The log-log data plot (Figure 3-4) shows the improvement rates and predictability which applies to a sample when a few hundred passes have been achieved. For any given drop-out level, it can be seen that the 3M tapes require fewer tape passes for the burnishing than the Dupont tape. (The 3M MTA 20478 tapes were experimental types that preceded the 971 product).

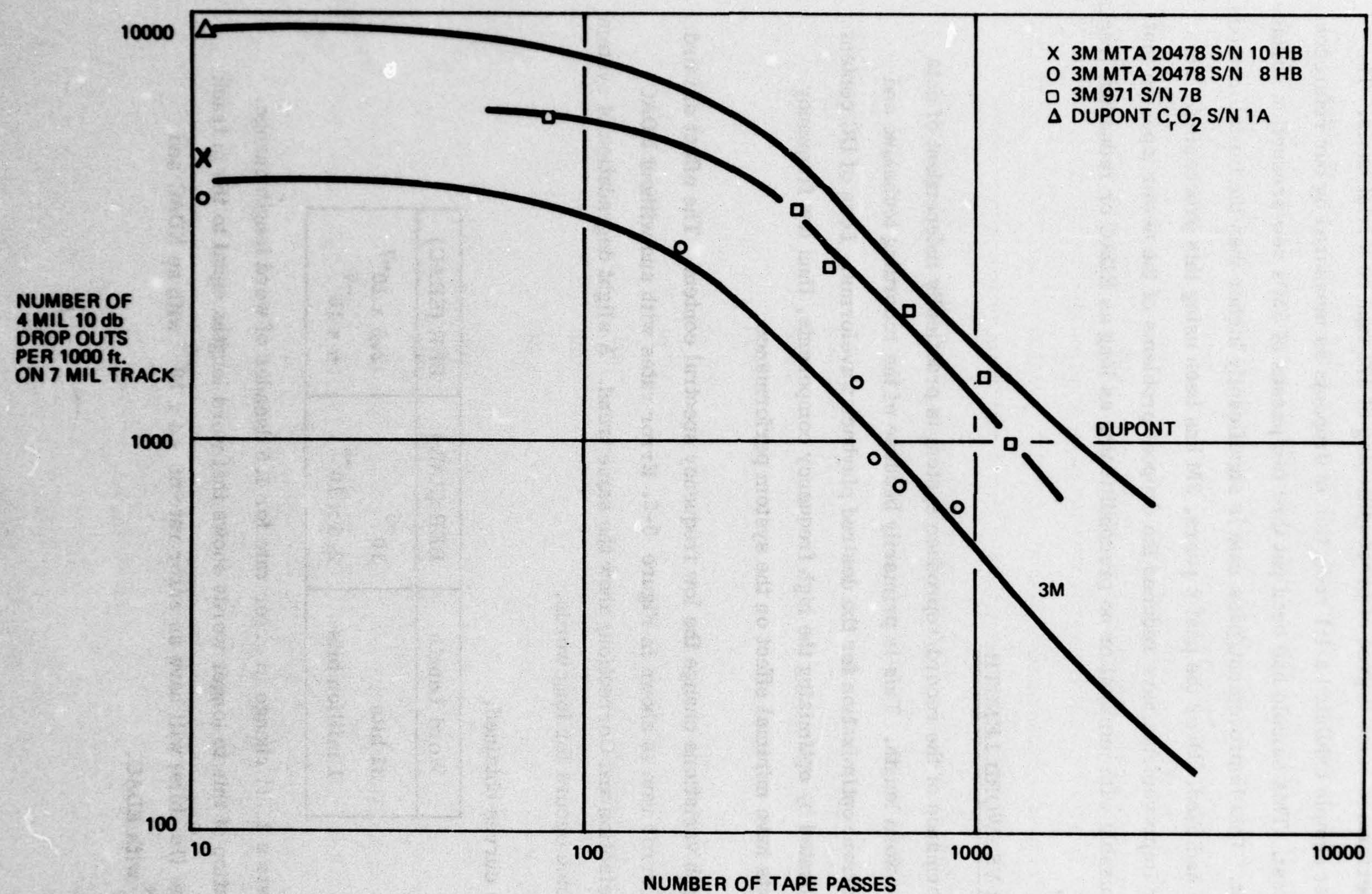


Figure 3-4. Magnetic Tape Drop Out Performance Improvement vs. Use (With Surface Conditioning and Magnetic Heads)

3M has performed some degree of preconditioning of 971 tape on a trial basis. The initial test sample exhibited a 4:1 reduction in dropouts as measured by our reference dropout test. This sample had been put thru two passes of 3M's new production surface treatment. This improvement/pass rate is significantly higher than the initial methods which we had used. Over the past 2 years, 3M has been using this processing. This and other improvements have reduced the dropout problems of the newer tapes so that they are usable with minimal or no preconditioning as long as EDAC or redundant tracks are used.

3.5 BER VS. WORD LENGTH

The performance of the record/reproduce system is practically independent of data content or word length. This is primarily because of the recording technique and record current optimization for the desired playback waveforms. Loss of DC content is compensated by optimizing the high frequency components, thus low frequency components have minimal effect on the system performance.

Word length variations change the low frequency spectral content. The effect of word length on error rate is shown in Figure 3-5. Error rates with and without EDAC (Error Detection and Correction) show the same trend. A slight degradation of system performance occurs for long words.

From the curves obtained,

Word Length	BER (RAW)	BER (EDAC)
31 bits	10^{-5}	2.5×10^{-7}
1 million bits	2.5×10^{-5}	6×10^{-7}

there exists a 2.5:1 change in error rate for 4.5 decades of word length change. Extrapolation of this to longer words shows that word lengths equal to the in track bit storage (10^9 bits) will have an error rate of $< 4 \times 10^{-5}$ with no EDAC and $< 1 \times 10^{-6}$ with EDAC.

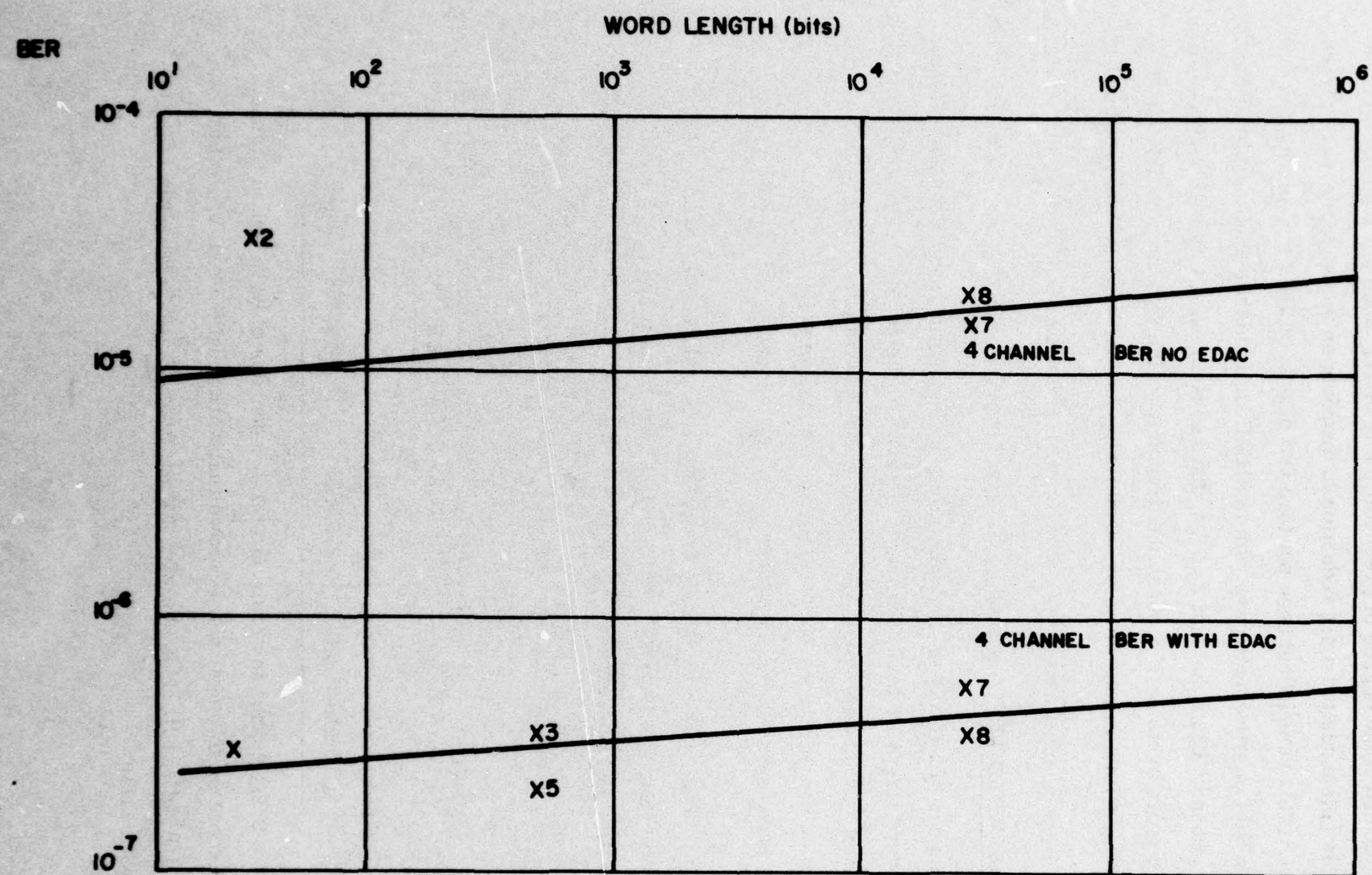


Figure 3-5. Bit Error Rate vs Word Length

4.0 ERROR PERFORMANCE MODEL

4.1 ERROR DETECTION AND CORRECTION (EDAC)

The finest tape transport and magnetic head design does not provide immunity to loss of data reproduced from tape when the tape is not perfect. Loss of signal on the tape itself or at the playback head for any reason introduces errors into the data. Since all available tapes contain imperfections (dropouts) that result in a loss of signal, it is inevitable that errors will occur if the dropout size is significant with respect to the data element size. For a multitrack recording system the usual tradeoffs between such parameters as bit rate per channel, tracking spacing, and reliable in-track packing density must be made taking into account available technology and system complexity. Optimization of the critical parameters resulted in a basic system approach that can be compared to measured error rates and distribution of dropouts. It has been determined that in order to attain required bit error rate repeatability with commercially available tape, some form of error correction is desirable. Error detection and correction (EDAC) techniques have been a powerful tool for communications and recording system designers for applications in which errors cannot be tolerated. Such techniques have been developed and implemented at RCA for a feasibility model recorder system.

An error model was constructed to determine the nature and distribution of droupouts. Prior to describing this error model, a general discussion of RCA head technology is presented.

4.2 HDMR HEADS/TAPE INTERFACE

Head technology has evolved around a configuration yielding an extremely high efficiency transducer. A typical video head, shown in Figure 4-1, is constructed with a very short magnetic path length, single turn-transformer coupled electrical connections, and high-permeability, high-wear-resistant materials.

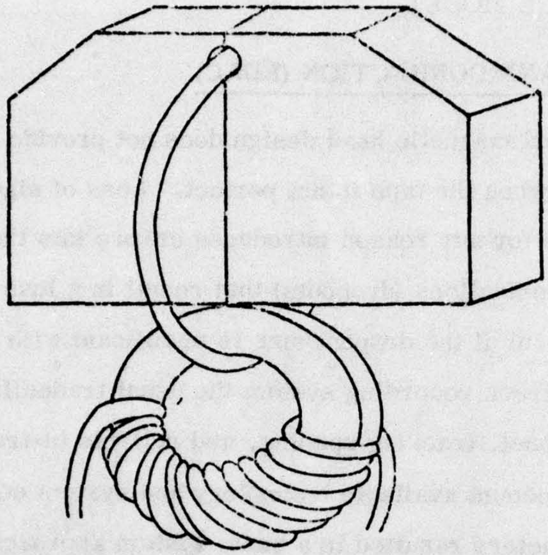


Figure 4-1. Video Recording Head

Video head fabrication technology has led to the development of complementary fabrication techniques for multichannel heads. Experimental multichannel record/reproduce heads have been fabricated at track densities of 58 and 82 tracks per inch, yielding track widths of 10 mils and 7 mils respectively. The HDMR head shown in Figure 4-2 is a batch fabricated, multichannel, unitized structure consisting of a single mechanical head containing a multiplicity of magnetically isolated transducers. The individual tracks are electrically connected via single turn loops to toroidal transformers located on alternate sides of the head. Shielding is required only between adjacent toroids because there is no material such as copper or permalloy to contact and contaminate the recording tape surface. Multichannel heads of this type may be fabricated with either Alfecon II or ferrites to obtain the desired efficiency. The choice is dependent upon the frequencies to be recorded.

When discussing the development of a high density recording system, it is necessary to treat the head and tape interface as an integrated system involving both mechanical and magnetic parameters of both head and tape. In order to capitalize on the resolution capabilities of modern submicron particle size high coercivity tapes, heads with

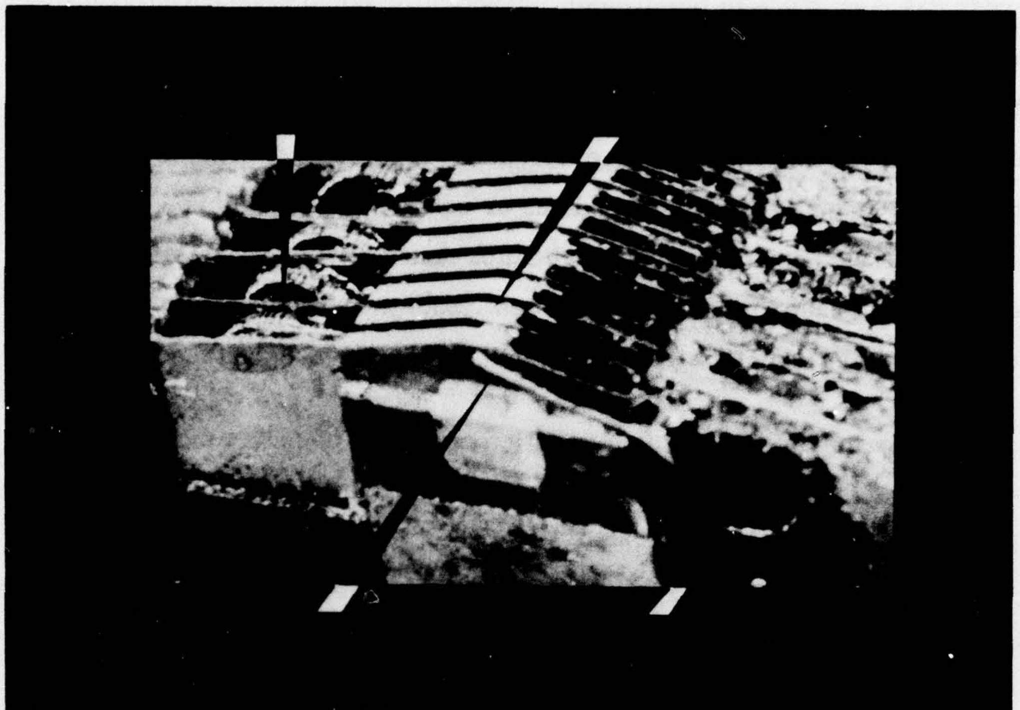


Figure 4-2. HDMR Head Details

submicron gap lengths and high efficiency magnetic circuits must be employed. Gap sizes as small as 0.2 microns are used with high energy (500 oersteds or higher) tapes to obtain adequate reproduce resolution as low as one micron wavelength. Subsaturation recording techniques are necessary in order to realize the optimum performance at wavelengths less than the thickness of the recording medium, since severe self erasure effects will occur when attempting to saturate the medium to depths beyond one wavelength. No attempt to discuss in detail the solutions to short wavelength recording is made here; however, discussion of certain head/tape interface effects related to high track density are necessary.

Excellent resolution capability and signal to noise ratio performance (function of particle size and dispersion) are now available from modern tapes. Improvements have also been made in tape life capability through improved binder systems. Very

recent progress has been made in the area of magnetically signal transparent positive coatings for magnetic recording tapes that extends the tape life up to 4 times and extend head life up to 5 times that when using untreated tapes. Tape dropouts caused by poor particle dispersion are a rare occurrence today. At very high packing densities severe dropouts may occur because tape nodules or contamination build up cause the tape to lift away from the gap surface. In high track density systems the effects of "tenting" due to contaminants and tape nodules contribute most significantly to errors because small defects represent a significant portion of small track widths.

Extensive tape testing to determine the distribution of head/tape defect size as a function of recorded wavelength has been conducted using both longitudinal and transverse scanning techniques. Results of these tests at a recorded wavelength of 2 microns are presented in Table 4-1 and Figure 4-3, and represent defect dimensions resulting in a 10 db signal loss.

TABLE 4-1. OCCURRENCE OF TAPE DEFECTS

Occurrence (Percent)	Number of Tracks with 10 db Signal Loss (12 mil track pitch)
1	4
9	3
30	2
60	1

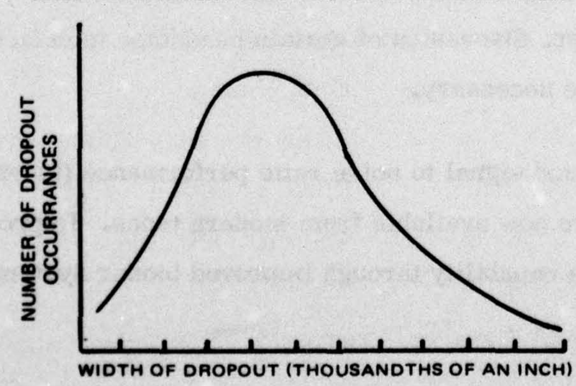


Figure 4-3. Dropout Occurrence vs. Dropout Width

Figure 4-3 indicates a distribution which closely fits a Rayleigh distribution with a maximum occurrence of 14 mils. From this data it would seem preferable to operate a recording system with track widths of at least 50 mils; however, it is known that a track width of only 5 mils is sufficient to obtain adequate performance (i.e., signal to noise ratio). Several alternatives to work around the defect size are suggested by the data of Table 4-1.

A straightforward method of increasing area packing density is to utilize spatial redundancy. Since the head-tape system provides adequate signal to noise ratio with 5 mil track widths and high immunity to defects at 50 mil spacing, a system which records redundant data on two narrow tracks separated by 50 mils will provide increased packing density with little or no decrease in performance. Figure 4-4 shows a possible format for spatial redundancy; the format shown would yield an area packing density of over one million bits per square inch.

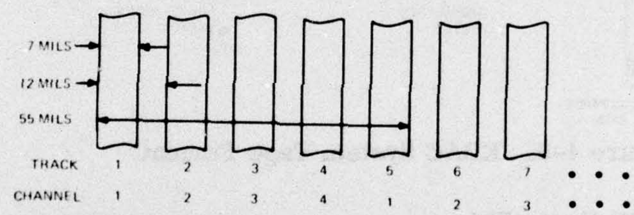


Figure 4-4. Spatially Redundant Recording

At the expense of additional electronics, a system which would yield a higher area packing density may be designed using error detection and correction (EDAC) techniques. The data presented in Table 4-1 shows that errors will occur in one, two, or three adjacent tracks for 99 percent of the defects. If the data read from n parallel tracks as an n bit parallel word, a code which is capable of detecting and correcting burst errors up to 3 bits in length would provide a reduction in bit error rate of approximately 100:1. A powerful class of EDAC codes for burst errors is described by C.M. Melas.[1] Table 4-2 shows the parity-bit efficiency of these burst error correction codes.

[1]Melas, C.M.; "A new group of Codes for Correction of Dependent Error in Data Transmission", IBM Journal (Jan 1960) pp-58-65

TABLE 4-2. ERROR CORRECTION EFFICIENCY

Total Bits	Info Bits	Parity Bits	Redundancy (Overhead)
15	9	6	0.4
63	55	8	0.127
255	245	10	0.04
1023	1011	12	0.012

A format utilizing EDAC is shown in Figure 4-5 where the format yields an area packing density of 1.75×10^6 bits per square inch at 25 kbpi when one inch tape is used.

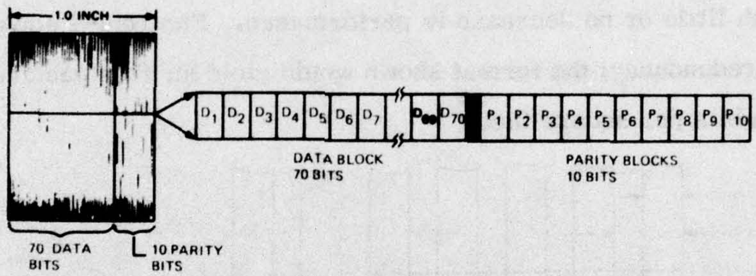


Figure 4-5. EDAC System Tape Format

4.2.1 Definition of Bit Error Rate

Errors in data can be classed as recoverable and nonrecoverable. The former are due to errors or failures during recording while the latter are due to similar problems during playback. For most data acquisition systems it is extremely important to minimize the former; however, the latter can usually be tolerated at some expense. Reproduce mode failures could be corrected or the tape could be reproduced on another unit (errors which are recoverable do not constitute mission failure).

4.2.2 Sources of Data Errors

Possible causes of data errors can be separated into two categories:

(1) electronics/mechanical failure (hardware); (2) tape and head/tape failure.

It is expected that hardware can be designed to meet high reliability requirements.

A tape and head/tape interface may inherently be unable to meet a required BER at the proposed track density because of head/tape separation caused by debris or tape surface irregularities.

As a result of these factors, the inherent BER is limited to approximately 1×10^{-5} in any system but the most conservative in BPI and/or tracks/inch. Special signal processing may be used to effectively improve tape and head/tape interface performance.

4.2.3 Track Width & Linear Packing Density

A bit error rate (BER) of 2×10^{-6} is not readily achievable with track width much less than 0.03 inches and/or intrack packing densities much greater than 20,000 bits per inch (BPI) unless the magnetic tape is carefully selected and/or specially processed to remove dropouts.

Smaller track widths cause typical dropout holes to cover a large portion of data track thereby reducing the reproduced signal severely. Unless a very large margin of signal to noise ratio (SNR) is available this will result in bit errors due to noise interference and, in the extreme case, will cause complete loss of signal.

High in-track densities require intimate head-to-tape contact to limit the amount of wavelength loss (54 db/λ), i.e., a typical system operating at 25,000 BPI or 40 microinches per bit will have a minimum wavelength of 80 microinches for delay modulation. A very smooth tape surface of 4 microinches plus a nominal head-to-tape separation of 4 microinches (for a total of 8 microinches) produces 8/80 x 54 or 5.4 dB of reproduce signal loss alone. A similar problem of a slightly different nature exists in record and produces variations in record transition locations and in record magnetization levels.

To obtain maximum usage of the magnetic tape medium it is desirable to maximize the track density (tracks/inch) and/or the in-track packing density (BPI). As noted above, increasing the former beyond about 20 tracks/inch (0.050 inch pitch allows for 0.045 inch track and 0.005 inch guard band) will reduce the BER to the tape dropout limitation which normally runs about 1×10^{-5} effective BER with $\pm$ 1 order of magnitude for poor tape and selected tape. A system requirement of minimum tape usage results in the proposed track density in the order of 50-100 tracks/inch which will require an error detection and correction (EDAC) or redundant track approach as outlined in the following sections. Either of these schemes adequately circumvents problems of tape dropouts while maintaining a maximum tape usage.

The maximizing of tape usage by maximizing in-track packing density (BPI) should be limited to operation at less than 20,000 BPI for minimum wavelength loss and minimum variations in wavelength loss (amplitude modulation effect). Using delay modulation (DM) coding (double density code) is effectively the same as 10,000 BPI for normal phase coding, or 10,000 cycles per inch (CPI).

This CPI range provides a relatively safe operation area and will result in a large safety factor for the head/tape system, thereby allowing the high reliability required to meet the proposed specification system.

Two solutions to achieving a low BER while yet maximizing tape usage are available in HDMR systems and are presented in the following section. The proposed solution also improves the effective hardware reliability by incorporating the allowance of single or multiple failures in the channel electronics and/or heads. This capability provides a graceful degradation of the equipment for many of the possible failure modes, thereby allowing for minimum down time during operational periods.

4.2.4 Redundant Heads vs. Error Detection and Correction

Since the basic error rate of a single magnetic track is well above the error rate desired for the entire system, some means must be devised to increase the reliability of the record/playback process. There are basically two approaches that have been used to achieve the desired goal: In the first approach, the individual information channel can be recorded in a redundant manner; that is, two separate tracks separated by a sufficient distance carry identical information. In the second approach error detection and correction techniques are employed to reduce the system errors to acceptable levels. Both of these approaches have their advantages and disadvantages which will be discussed in the paragraphs below.

Recording the primary digital data in a redundant manner has great appeal since the basic technique involved is simple and straightforward. If the redundant tracks are not separated by too great a distance, the effects of static and dynamic tape skew are minimal and thus do not require individual correction. It will, however, be desirable to use individual record amplifiers to achieve optimum record current for each of the heads. On playback, individual preamplifiers will also be required so that it will be possible to monitor that each of the tracks is recorded and reproduced properly. The output signals from the two preamplifiers could then be combined in a linear network and be treated as a single channel. Again assuming that the individual tracks are separated sufficiently, an individual track error rate of one part in 10^5 will yield a channel and system error rate of one part in 10^{10}, an individual track error rate of 10^4 will yield a system error rate of 10^8. Practical experience indicates that tape dropouts will occasionally cover large areas so that the improvement factors stated above cannot be fully realized.

The error detection and correction (EDAC) technique is more complex as far as electronic circuitry is concerned, yet requires a reduced number

of tracks to achieve comparable improvements in system error rates. Various EDAC systems available will handle bursts of errors, defective channels, or combinations thereof. One particular system highly suitable for this application is described in detail in paragraph 4.3.2. It is also noteworthy that this particular EDAC system requires a very limited amount of extra circuitry in the encoding (record) portion of the equipment. In the decoding (error correction) phase the amount of circuitry is reasonable.

In addition to considering the basic techniques that can be used to reduce the error rate, it is important to relate the total information that must be stored on tape to parameters such as tape speed, the size of reels, and the information packing density on each track. Table 4-3 summarizes the tradeoffs. It should be noted that, for a given tape speed, the redundant recording technique calls for appreciably higher information packing density than the EDAC approach. Also, a higher tape speed yields a reduced recording time on a standard 16 inch reel (recording time stated here does not include tape usage due to acceleration and deceleration of the tape).

TABLE 4-3. TRADEOFF DATA FOR TRACKS, TAPE SPEED, AND TECHNIQUE

Tape Speed ips	Reel Diameter for 10 Min. Recording (Inches)	Recording Time on 16 Inch Reel	Information Packing Density for Primary Digital Data Kb/in.	
			EDAC	Redundant
			112 Information +14 EDC	80 Information +80 Redundant
			126 Tracks	160 Tracks
150	12.5	16	14.3	20.0
120	11.5	20	17.8	25.0
107	10.5	23	20.0	28.0

Using these considerations, the optimun approach for recording digital information is based on a nominal tape speed of 100 ips using the EDAC technique. The alternate to this system would provide less record time at a tape speed of 150 ips using redundant track techniques. The following paragraphs discuss in detail the error rate improvements using the EDAC and redundant head approaches.

4.2.5 EDAC Performance

Error detection and correction (EDAC) techniques can readily be applied to longitudinal track recorders by considering the bits which occur simultaneously in all the tracks across the tape as a code word consisting of both data and EDAC bits. The particular EDAC technique selected is dependent on the type of errors that occur in the tracks. Based on data taken with recording systems similar to the one considered, the following error model was obtained.

(1) The errors are primarily due to tape dropouts.

(2) The dispersion of tape dropouts is such that, for a single track, the probability of a tape dropout occurring for a particular bit is 1×10^{-4}. Since there is a 0.5 probability of the bit being in error when a dropout occurs, the bit probability for a single track would be 5×10^{-5}.

(3) The average dropout is 0.014 and less than 0.036 inches in diameter 99 percent of the time.

Assume that the design goal for bit error probability, if the EDAC technique is used, is 1×10^{-6}. It is also desirable to have a small error probability when one of the tracks has failed. An EDAC technique, which can be implemented reasonably, is described in detail in paragraph 3b. Basically, the channels are arranged into two groups: Group 1 covers digital tracks 1, 3, 5...125; Group 2 covers digital tracks 2, 4, 6...126. In this way tape

dropouts which cover 2 or 3 adjacent tracks will be broken up. Each EDAC group of 63 bits contains 7 parity bits and has the capability of correcting two errors in the group. For the measured error model this EDAC code will provide bit error probabilities predicted in the following paragraph.

4.2.6 Bit Error Rate Prediction

The error detection and correction technique selected was based on the error model described in paragraph 3 and the spacing of the longitudinal tracks on the 2-inch tape. The selection was based on a final bit error rate after correction of 1×10^{-6}, minimum number of added tracks for EDAC, and reasonable circuit complexity.

Experimental tests were conducted to determine the error profile to substantiate the error model. These tests consisted of looking at the errors corrected by the EDAC to determine whether they were single, double, or triple burst errors. The first series of tests, conducted look at errors corrected by the EDAC, indicated that the error model of 60 percent single errors, 30 percent double errors, and 10 percent triple errors was approximately correct. A second series of tests conducted looked at errors when EDAC was exceeded. The results indicated errors occurred in 2 or 3 channels in a group of 4 or 8 adjacent channels. Some of the errors (2 or 3 errors in a group of 4) could be interpreted as very large tape dropouts going across 4 channels, and other errors could be interpreted as two or three random errors occurring simultaneously across tracks. In either case, they occurred so seldom that they have very little effect on the EDAC error model.

The experimental data obtained has indicated that the occurrence of two tape dropouts or separated errors across the tape simultaneously follows a random basis.

For a 126-track system, a dual 2-bit correction interlaced EDAC system is sufficient since less than 0.01 percent of the dropouts would cover more than 4 tracks.

Figure 4-6 shows the system bit error rate after EDAC has been applied as a function of a single track bit error rate for the 160 channel test system with 3-bit burst EDAC, and the proposed 126-channel dual 2-bit burst interlaced system. It can be seen that the proposed system error rate can be obtained with a single channel error rate of 8×10^{-5}.

4.2.7 Error Rate for Single Channel Failure

The Error Detection and Correction technique selected for a 126 track system has the capability of maintaining the specified error rate in one of the EDAC channels and a reasonable error rate in the other channel when a track channel failure occurs. Without the EDAC the failure rate would become very large if one of the recorder channels failed. For no EDAC and the data spread over 112 channels the error rate would become $\frac{1}{2} \times \frac{1}{112} = 4.5 \times 10^{-3}$. The 1/2 term considers that even for a failed channel the playback circuitry assumes either a 1 or 0 and thus one-half of the time would be correct. With EDAC, when a channel fails the EDAC system not affected will still meet a 1×10^{-6} bit error rate. The total BER would only degrade to $0.8\ P_e$ where P_e is the single channel error rate. For an anticipated P_e of approximately 2×10^{-5} the system error rate would become 1.6×10^{-5} which would still provide operation with a reasonable error rate. Without EDAC the affected channel error rate would be 4.5×10^{-3}, with EDAC the decrease to 1.6×10^{-5} is a 280 to 1 improvement in system error rate. The following calculations show the derivation of the above numbers.

The dropout error model used is that discussed in the analysis of the system error rate for the 126 channel system. The system error rate without

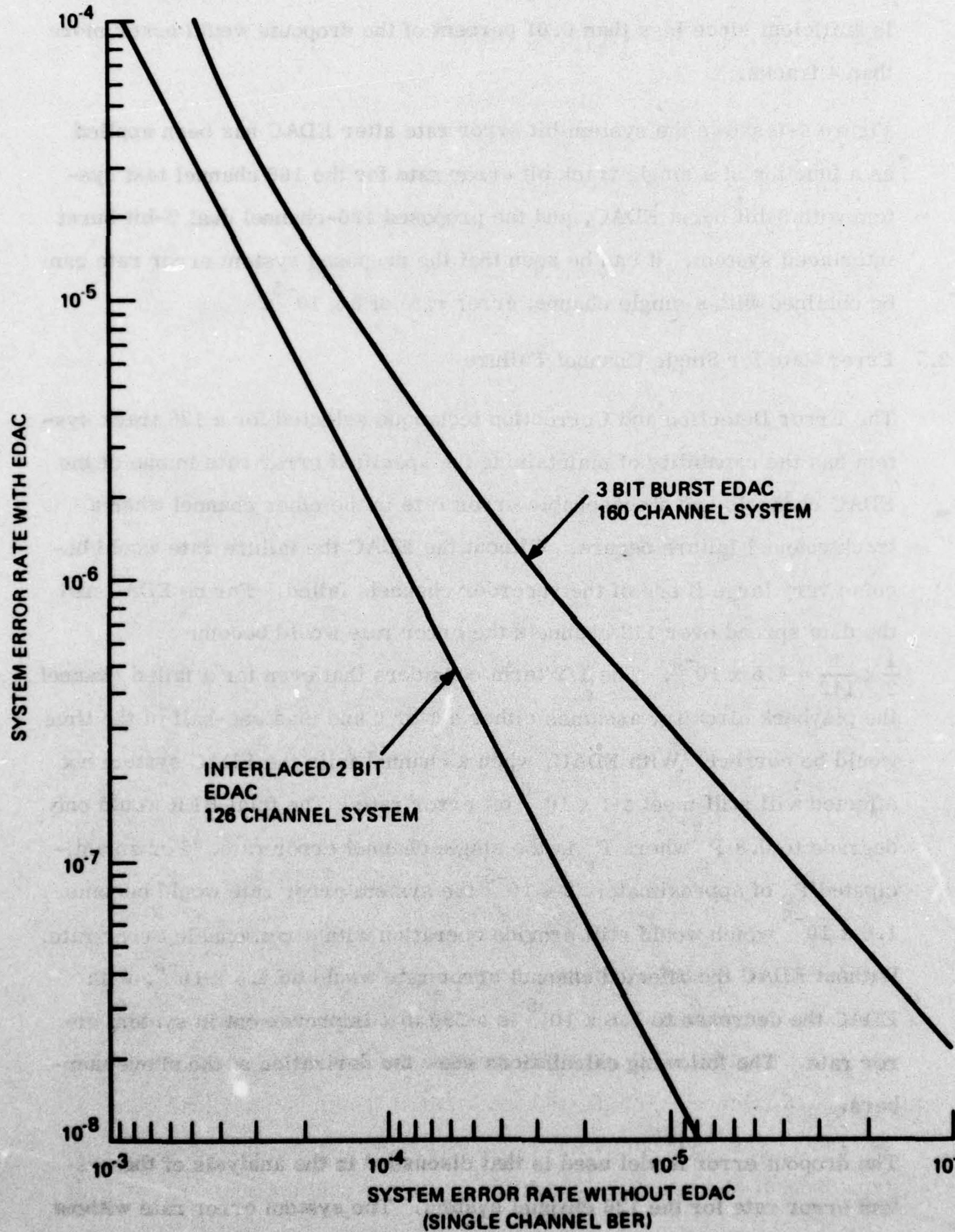


Figure 4-6. System BER with EDAC vs. Single Channel BER

a failed channel was

$$P_s = 1.6 \times 10^{-4} P_e + 1.48 \times 10^2 P_e^2 + 6.64 \times 10^{-3} P_e^3$$

When a failed channel occurs, the data in that channel will be incorrect one-half of the time. If no other errors occur in other channels the EDAC will correct the data in the failed channel. If other errors occur, the EDAC will be unable to correct both the errors of the failed channel and those caused by other sources such as tape dropout. The number of times that errors occur will be $1/2\ P_e$; when they occur there will be two uncorrected errors plus an average of 1.2 bits made incorrect by the EDAC subsystem. The overall system error rate becomes

$$P_s = 1.6\ P_e$$

for the EDAC system with the failed channel. The total recorder BER than will be 1/2 the $1.6\ P_e$ bits or $0.8\ P_e$.

4.2.8 Redundant Head Performance

As previously stated, at comparable BPI operation the redundant head approach requires a higher tape usage (speed) by a factor of 150/107 or 140 percent. The fewer channels of electronics required (80/126) reduces the electronics recurring costs somewhat, but is partially offset by increased head costs (160 tracks/126 tracks) and tape cost. The lesser number of electronics channels could also reflect somewhat in less maintenance and improved reliability.

Exclusive of the above considerations, performance of the redundant head approach can be calculated from the same model used for calculation for the EDAC approach. Slight differences in track width have little effect on BER performance. For the 160 track model the single track BER is 5×10^{-5}. The redundant tracks would be separated adequately so that a tape dropout or head/tape separation problem would not likely affect both.

Assume that for a spacing of 4 tracks a dropout will span this area 1.0 percent of the time. This will produce a BER of $1 \times 10^{-2} \times 5 \times 10^{-5}$ or 5×10^{-7} under normal conditions. If one track were to go bad, (includes record amp, heads, and preamp) the loss of a channel of electronics would not be compensated for and the channel concerned would revert back to the tape dropout BER of 5×10^{-5}. For one channel at 5×10^{-5} and the other 79 channels at 5×10^{-7}, a system BER of 6×10^{-6} is obtained producing a system "soft" failure condition.

In the above discussion the BER due to the SNR of the channel is considered to be negligible. The 3 dB gain in SNR for redundant heads and the 3 dB loss in SNR for one head failure or dropout will not cause significant effects on the channel BER due to the SNR margin available.

4.3 ERROR MODEL

Extensive tests with a 164-track head were made to determine the nature and distribution of dropouts. From the test data, the following conclusions have been drawn:

- The errors are primarily due to head/tape dropouts.
- Since there is a 0.5 probability of the bit being in error when a dropout occurs, the bit error probability for a single track would be one-half the probability of being in a dropout.
- The size of the dropout follows a Rayleigh distribution with a probability density function of

$$P(R) = \frac{R}{\sigma^2} e^{\frac{-R^2}{2\sigma^2}}$$

where R is the size of the dropout and the standard deviation, σ, is 14.4×10^{-3} inches.

Of maximum importance is the determination that only 1 percent of the dropouts will be greater than 36 mils in width. Subsequent experimental data obtained with the feasibility

recording system verified the early data and yielded additional data relating to probability of multiple dropouts occurring across the tape.

This data in all important parameters has shown close correlation to data and theory available in the literature such as:

1. "An Examination of dropouts occurring in the magnetic recording and reproducing process" by W. Van Keuren, JPL, Pasadena, California (under NASA Contract NAS 7-100)

2. "Drop-outs in Magnetic Recording" by R.H. Carson, U.S. Naval Research Labs., Int. Conference on Magnetic Recording, July 1964.

The probability distribution for the 164 track test system (7 mil tracks on 12 mil pitch) in terms of dropout size R is as follows.

Dropout Size R (mils)	Tracks Covered by Dropout	Probability
$R < 19$ (1.5 tracks)	1	0.58
$19 < R < 31$ (1.5 to 2.5 tracks)	2	0.32
$31 < R < 44$ (2.5 to 3.5 tracks)	3	0.09
$44 < R$ (greater than 3.5 tracks)	4 or more	0.01
		1.00

For a 126-channel system (112 data plus 14 EDAC) the tracks will have an 8 mil width, 6 mil guard band, and 14 mil pitch. For this 126 channel system the error model would have the following distribution.

Dropout Size R (mils)	Tracks Covered by Dropout	Probability
$R < 21$ (1.5 tracks)	1	0.655
$21 < R < 35$ (1.5 to 2.5 tracks)	2	0.293
$35 < R < 49$ (2.5 to 3.5 tracks)	3	0.049
$49 < R < 63$ (3.5 to 4.5 tracks)	4	0.0029
$63 < R$ (greater than 4.5 tracks)	5 or more	0.0001
		1.0000

4.3.1 EDAC CODE DESCRIPTION

The EDAC system selected, consists of two identical independent EDAC subsystems with each handling one-half the total data tracks, but the data tracks will be interlaced on the tape so that every other track is handled by one of the subsystems. Each of the two interlaced error correction subsystems is obtained from the following generating polynomial:

$$g(X) = (X^6 + X + 1)(X + 1)$$

This is a 63 bit code with 56 data bits and 7 EDAC bits.

Six parity bits will be obtained from the $X^6 + X + 1$ generator polynomial and the seventh from the X+1. Each of the first 6 parity bits provides parity for approximately half of the 63 total bits and the seventh for all 63 bits. The location of the particular bits that a parity bit checks may be obtained by using the generator polynomial. Let $b_1, b_2, \ldots b_{63}$ represent the 63 bits in an EDAC group. *Associated with each group is a binary code location sequence* **$C_1, C_2, \ldots C_{63}$. The associated bit, b_n, will be checked if $c_n = 1$.**

Six of the parity bits are obtained from $X^6 + X + 1$. The corresponding code location sequence follows

$$c_n + 6 = c_n + 1 \;\theta\; c_n$$

where θ indicates "modulo 2" addition or the "exclusive OR" function. The equation can be changed to

$$c_n = c_n^{-5} \;\theta\; c_{n-6}$$

The code sequence repeats itself after 63 bits and it is possible to start anywhere in the 63 bit sequence. The starting point selected for P_1 is

$c_1 = 0,\ c_2 = 1,\ c_3 = c_4 = c_5 = c_6 = 0$. Thus $c_7 = 1,\ c_8 = 1,\ c_9 = 0$, etc. for P_1.

The code sequence for P_2 is moved over 1 bit from P_1. Thus,

$$c_n(P_2) = c_{n-1}(P_1)$$

$$cn(P_3) = c_{n-1}(P_2) = c_{n-2}(P_1)$$

$$c_n(P_4) = c_{n-1}(P_3) = c_{n-3}(P_1)$$

$$cn(P_5) = c_{n-1}(P_4) = c_{n-4}(P_1)$$

$$c_n(P_6) = c_{n-1}(P_5) = c_{n-5}(P_1)$$

The following table shows the first part of the code location sequence.

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9 ....
P_1	0	1	0	0	0	0	1	1	0
P_2	0	0	1	0	0	0	0	1	1
P_3	0	0	0	1	0	0	0	0	1
P_4	0	0	0	0	1	0	0	0	0
P_5	0	0	0	0	0	1	0	0	0
P_6	1	0	0	0	0	0	1	0	0

Each of the 63 bits is checked by 1 to 6 of the parity bits with an average of 3 parity checks. Parity bit P7 checks all 63 data plus EDAC bits. Upon decoding, the bits are all checked to determine if an error has occurred. If no error has occurred, all 7 parity checks will pass okay. However, if an error has occurred, some of the parity checks will be bad. P_7 determines the type and P_1 through P_6 determine the location of the error. If a single error has occurred P_8 would be a 1 and if a double error has occurred P_8 would be a 0. For example, if bit b_8 is in error, the parity checks P_1 through P_7 will result in 1, 1, 0, 0, 0, 0, 1 respectively. P_8 indicates it was a single error and the first 6 parity checks

indicate the location of the error. When this exact pattern is present, the EDAC decoder recognizes it and corrects bit b_8. Each of the 63 single bit errors and 62 double bit errors will be uniquely identified by a seven bit error pattern. Once the error pattern is recognized, the bits in error are corrected.

4.3.2 EDAC IMPLEMENTATION

This EDAC system consists of two identical independent EDAC subsystems with each handling one-half of the total data tracks. The following describes one of the subsystems. The EDAC encoder block diagram is shown in Figure 4-7. Each of the 7 parity bits is generated by logic which calculates the parity over the channels assigned to that parity bit by the code location sequence discussed in paragraph a. There will be approximately 27 of the 56 data channels assigned to each of the first six parity bits, and all the 56 data channels assigned to P_7. After the parity bits have been determined for the data, the parity bits check each other to obtain 7 parity channels which completely check all 63 data plus parity bits. The EDAC decoder block diagram is shown in Figure 4-8. The EDAC decoder accepts the 63 channels of data and parity bits, determines which channels are in error and corrects them. (The mathematics for the parity checks are described in paragraph a).

All 7 parity bits are checked simultaneously, but parity bits 1 thru 6 are treated separately from parity bit 7. The P1 thru P6 parity bits have $2^6 = 64$ possible patterns. P7 could be either a 0 or 1. If all parity bits check good, then no errors have occurred, however, each of the possible 63 single bit error and 62 double bit error patterns will be uniquely identified by a combination of the parity bits. For example, there are 3 different error patterns which would indicate that channel 28 is in error. Whenever any one of these 3 different error patterns is recognized it will be known that channel 28 has an error and a signal will be sent to the channel 28 bit correction circuitry to correct the

error. The largest amount of circuitry in the EDAC decoder is used to determine which bits are in error after the parity bits have been determined. Propagation delay calculations have indicated sufficient time to permit the circuit to calculate the errors during a one-half bit period.

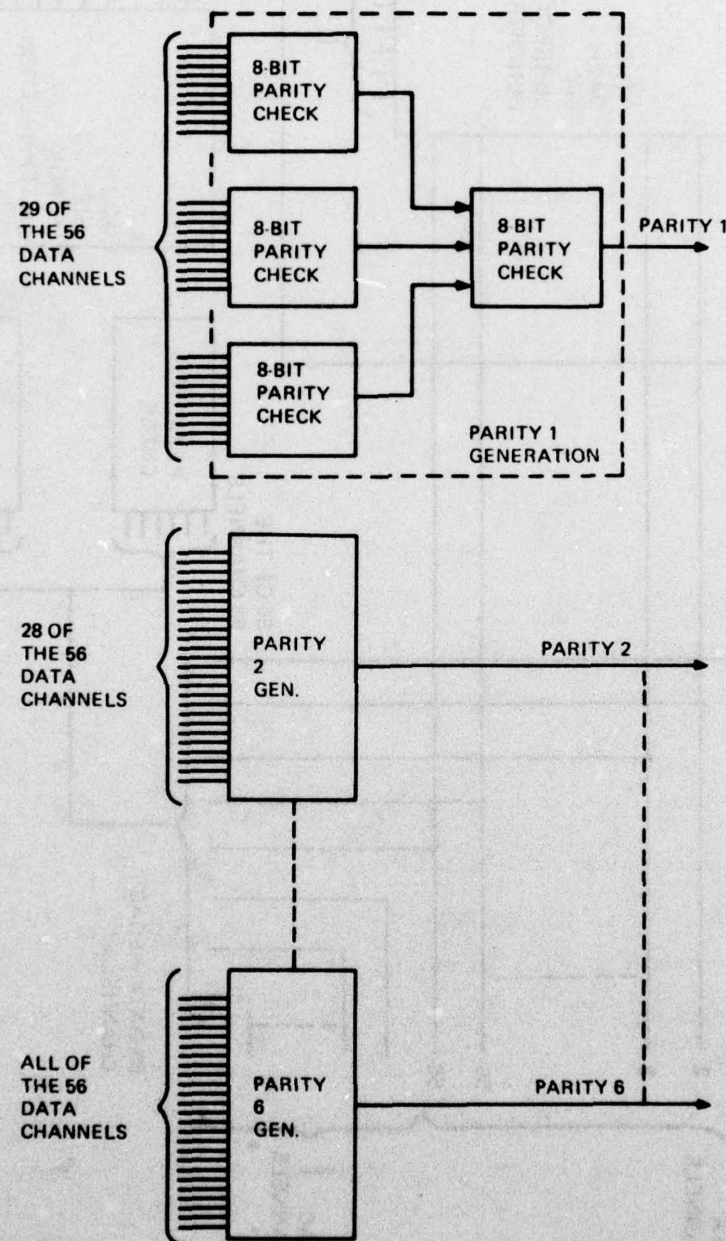


Figure 4-7. EDAC Encoder Block Diagram

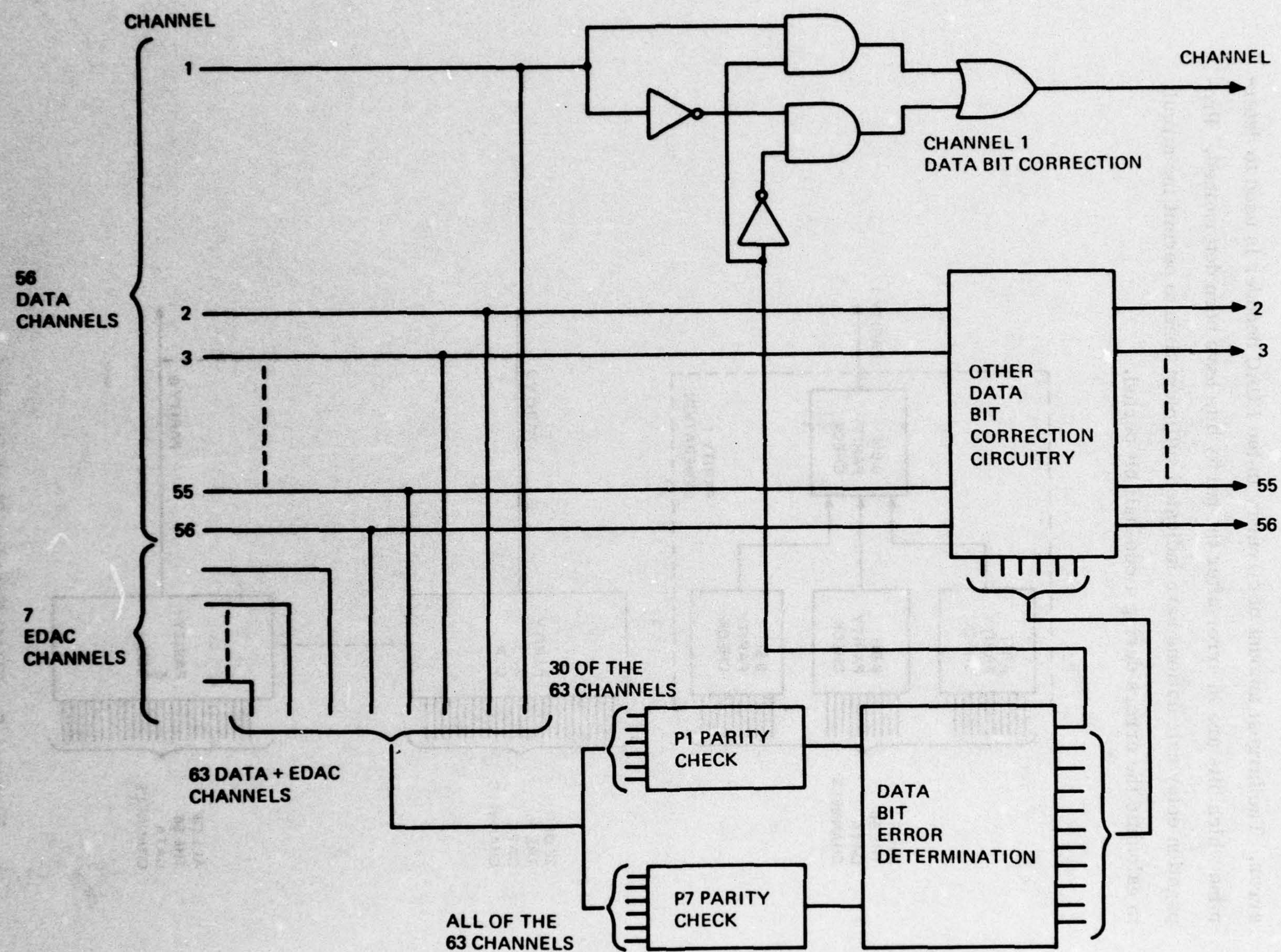


Figure 4-8. EDAC Decoder Block Diagram

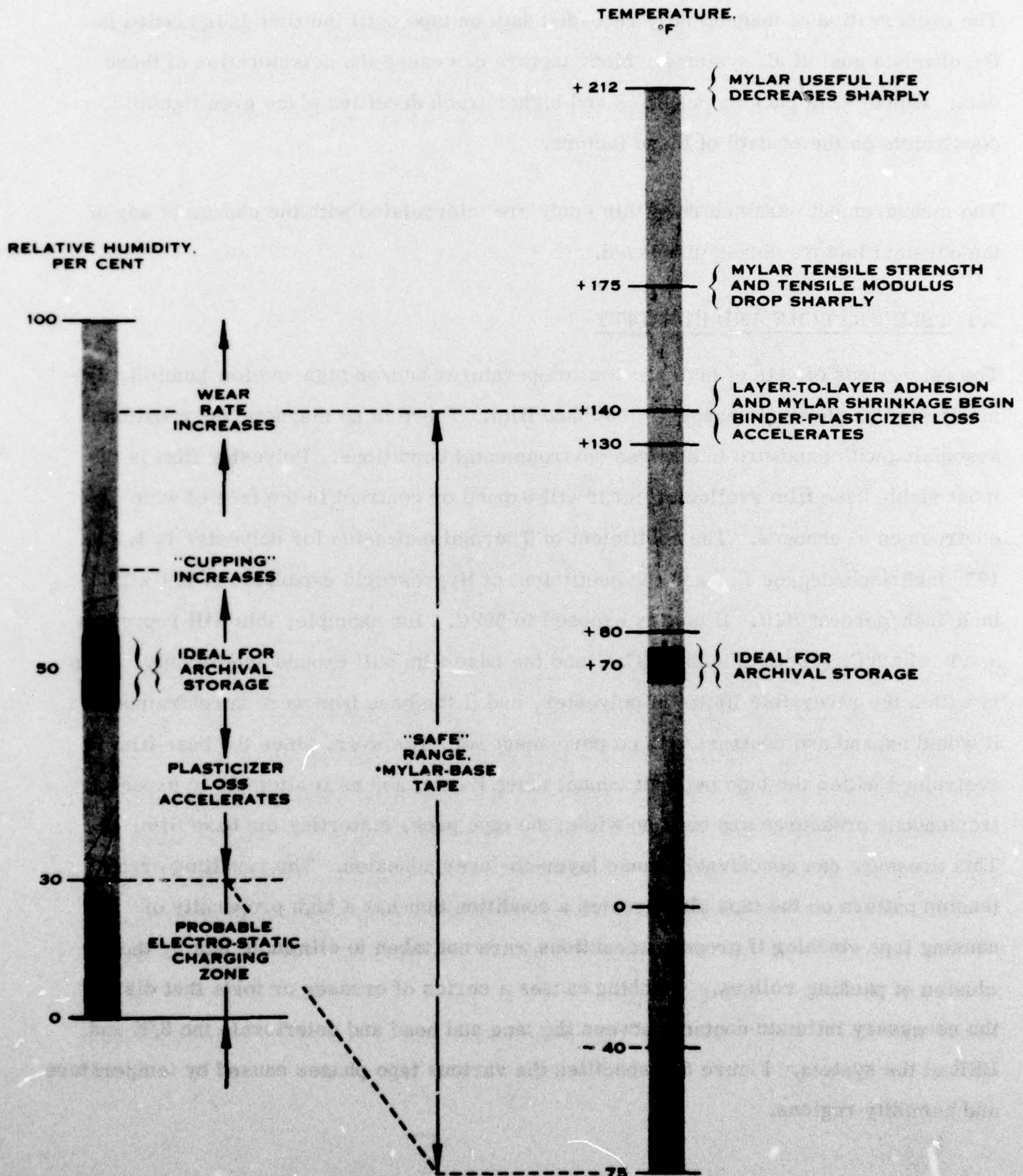
5.0 TAPE STORAGE

The preservation of magnetically recorded data on tape until the time it is needed is the ultimate goal of all systems. Many factors can cause the deterioration of these data. Higher data packing densities and higher track densities place even tighter constraints on the control of these factors.

The measurement parameters of this study are interrelated with the change of any of the physical factors herein discussed.

5.1 TEMPERATURE AND HUMIDITY

The deleterious effects of high and low temperatures and/or high and low humidity are manifested as physical changes in the base film. There is no magnetic degradation associated with exposure to adverse environmental conditions. Polyester film is the most stable base film available, but it will expand or contract in the face of wide environmental changes. The coefficient of Thermal expansion for polyester is 1.5 x 10^{-5} inch/inch/degree F., and the coefficient of *Hygroscopic expansion* is 1.1 x 10^{-5} inch/inch/percent R.H. If tape is exposed to 50°C., for example, this will represent a ΔT of 25°C. (50°C. minus 25°C.), and the base film will expand accordingly. This is within the reversible limits of polyester, and if the base film were unrestrained it would expand and contract with no permanent set. However, since the base film is restrained within the tape pack, it cannot move freely; and as it attempts to expand, tremendous pressures are built up within the tape pack, distorting the base film. This pressure can conceivably cause layer-to-layer adhesion. The resulting erratic tension pattern on the tape also creates a condition that has a high propensity of causing tape cinching if proper precautions were not taken to eliminate this by the inclusion of packing rollers. Cinching causes a series of creases or folds that disrupt the necessary intimate contact between the tape and head and deteriorate the S/N and BER of the system. Figure 5-1 specifies the various tape phases caused by temperature and humidity regions.



(COURTESY AMPEX CORPORATION)

Figure 5-1. The Effect of Environment on Magnetic Recording Tape

While the "self-ignition" temperature of polyester-backed tape is in the neighborhood of 1000°F., temperatures below that point can still cause damage. Polyester film will shrink 1-1/2 percent at 300°F., and 25 percent at 325°F. If a roll of tape is heated to the approximate temperatures listed below, certain effects would be noted when the roll had cooled.

250°F — Backing distortion.

320°F — Softening of both the backing and binder with some "blocking" or adhesion of adjacent layers.

550°F — Darkening and embrittlement of the backing and binder.

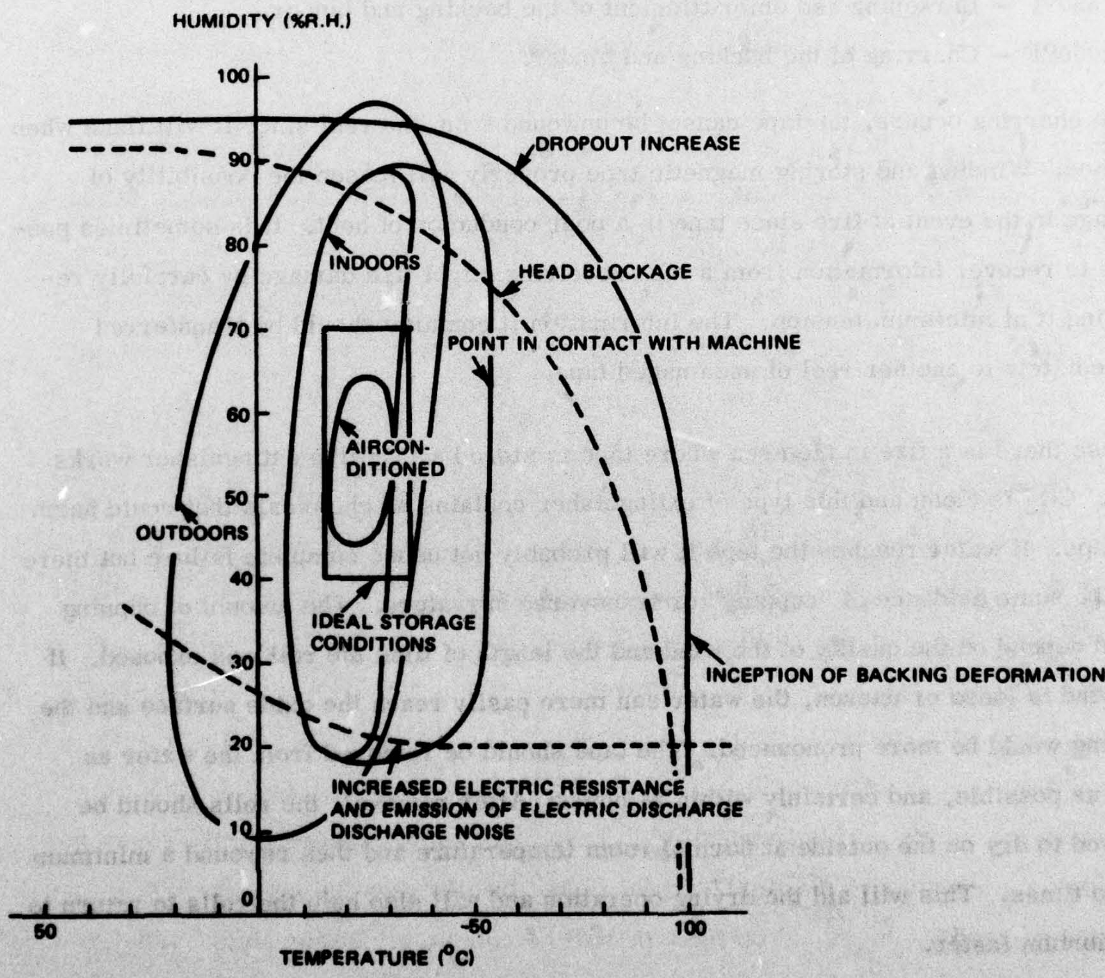
1000°F — Charring of the backing and binder.

When charring occurs, the tape cannot be unwound from the reel since it will flake when touched. Winding and storing magnetic tape properly will lessen the possibility of damage in the event of fire since tape is a poor conductor of heat. It is sometimes possible to recover information from a tape receiving slight fire damage by carefully rewinding it at minimum tension. The information it contains should be transferred immediately to another reel of undamaged tape.

In case there is a fire in the area where tape is stored a CO_2 fire extinguisher works best. CO_2 is clean and this type of extinguisher contains no chemicals that could harm the tape. If water reaches the tape it will probably not cause complete failure but there may be some evidence of "cupping" or transverse curvature. The amount of cupping would depend on the quality of the wind and the length of time the roll was exposed. If the wind is loose or uneven, the water can more easily reach the oxide surface and the cupping would be more pronounced. The tape should be removed from the water as soon as possible, and certainly within 24 hours: After removal, the rolls should be allowed to dry on the outside at normal room temperature and then rewound a minimum of two times. This will aid the drying operation and will also help the rolls to return to equilibrium faster.

If a temperature increase occurs while the tape is water soaked, more damage can be caused. A temperature in excess of 130°F., with a relative humidity above 85 percent may cause layer to layer adhesion as well as some physical distortion. (1)

Combinations of various temperatures and humidities as related to certain conventional environments are outlined in Figure 5-2. Regions of dropout increase, backing deformation, head blockage, and static change are indicated.



(COURTESY FUJI PHOTO FILM USA, INC.)

Figure 5-2. Storage Conditions and Effects on Tape Properties

5.2 CHEMICAL ENVIRONMENT

The polyester base material is relatively chemical inert but the organic binder is susceptible to deterioration by acetone and MEK. Most binders will withstand isopropyl alcohol and Freon TF. Freon TF is one of the fluorinated hydrocarbon solvents that is non-flammable, non-explosive, relative non-toxic and stable in use. It is a selective solvent good for oils, greases and many other organic compounds, yet it has little effect on elastomers, plastics and metals.

5.3 STRAY FIELDS

Different types of stray fields affect tape in different ways. The first field to consider is a steady DC field, such as that produced by a permanent magnet. If a reel of tape remains within a DC field, the resultant effect is that an extra signal is recorded on the tape. This will take the form of background noise, and will vary in strength in proportion to an exponential of the applied field and proportional to the length of time the field is applied. This will be similar to the effect that a magnetized recording head which was not properly degaussed will have on tape during recording. This points up the need and advisability of degaussing heads frequently.

A different phenomenon occurs when tape is exposed to an AC field. If a tape is moved rapidly through an AC field, the effect is about the same as recording on the tape without using AC bias. A highly distorted time variant signal can be left on the tape. This noise is recorded in much the same manner as significant data coming through the record head in normal operation. With a stray AC field present, the possibility of erasure always exists, and the degree of erasure is nonlinear with respect to the AC field strength. If the peak strength of the field is less than the coercivity of the tape, it is impossible to have a complete erasure regardless of how long the tape remains in the field. In AC fields greater than the tape coercivity (usually 250-260 oersteds), the signal on the tape will be completely obliterated. Tape erasure in an AC field may be considered a time function. A brief exposure to a 700-1000

oersted field will completely erase the signal on the tape, whereas longer exposures to weaker fields will be required for complete erasure.

Another effect suffered from exposure to stray fields is that of increased print-through. This can occur at relative small field strengths. For instance, a five minute exposure to an RMS field of 20 oersteds will cause a print-through increase of 10 db. The print-through increases roughly at the rate of 2 db for every additional 5 oersteds.

The effect on tape of the earth's magnetic field of approximately 0.5 oersteds is negligible. Generally stated, a stray field of up to approximately 10 oersteds should have no detrimental effects on magnetic tape. When tape is exposed to more powerful fields, up to about 100 oersteds, low-level and short wave length signals may be erased. As the field strength increases, the longer wave-length and higher level signals will be affected. Field strengths of 700 oersteds or more will completely destroy all magnetic data previously recorded on the tape.[2]

Other radiated energy can have adverse effects on recorded tapes and are:

(1) Microwave electromagnetic fields are ineffective for magnetic tape signal destruction unless the tape is extremely close to the antenna. This is because the magnetic component of the field loses its strength very rapidly with distance from the antenna. In one series of tests groups of recorded tapes were placed in various positions at a distance of approximately 450m (1500 ft) from a 5 million watt, pulsed radar antenna. They remained there for 27 days and were then subjected to a number of rigorous tests including signal-to-noise, print-through and signal amplitude; no detrimental effects were observed.

(2) Nuclear radiation is ineffective as a magnetic tape signal destroying force except, of course, where physical destruction of the tape backing or oxide can occur. The electromagnetic field associated with a nuclear burst is not sufficiently strong to produce signal erasure, although its irradiation effects may cause damage to the oxides or backing.

(3) Magnetic field emanating from the airport metal and gun detector systems are too weak to cause destruction of the signal on a recorded computer tape. For example, one such system produces a field intensity of less than 80 A/m (1 oersted).

(4) Available information on the effects of lightning strokes on recorded magnetic data indicates that the tape must be within 3.05 m (10 ft) of the center of the bolt in order to sustain observable damage and within 0.91 m (3 ft) before severe erasure occurs. The current at the center of the bold is approximately 10^5 amperes.

(5) Excessive temperatures can cause signal loss especially as the Curie temperature of the iron oxide in the tape is approached. In fact, there is a method of recording on magnetic tape known as "thermoremanent" or "Curie Point" recording in which the oxide is heated to approximately 675°C. Near this temperature a very small magnetic field can either magnetize or demagnetize a tape. However, the base material of the magnetic tape will undergo physical damage and deformation at much lower temperatures. [3]

5.4 HANDLING

Poor handling or faulty storage procedures can render a tape useless because of physical damage. The recorded information does not tend to fade or weaken with age. It is essentially permanent and will remain unchanged until actually altered by an external field, whether it be done intentionally or accidentally. Some of these controlable factors are as follows:

5.4.1 TENSION

One tape manufacturer recommends a wind tension that is relatively low. Six to eight ounces per 1/2 inch of tape width is sufficient to render a firm, stable wind. This tension, while great enough, does not result in high pressures within the roll that could permanently distort the polyester backing. Backing distortion, caused by extreme pressures within the tape pack may resul. if a

roll of tape wound too tightly was subjected to an increase in temperature while in storage.

Just as there is the possibility of problems if the tape tension is too great, too low a wind tension can cause difficulty as well. If the wind is too loose, slippage can occur between the tape layers on the reel. This "cinching" as it is called, can permanently damage the tape by causing a series of creases or folds in the area that has slipped. When the roll is unwound, the surface will be wrinkled. When an attempt is made to use the tape again, the wrinkles and creases will disrupt the necessary intimate contact between the tape and the head. Because the tape is repeatedly lifted from the head, the result will be a series of dropouts. If, immediately after an occurrence of cinching, the tape is properly rewound, there is a possibility that the information may be saved.

Along with proper tension, another important consideration is wind "quality." The successive layers of tape should be placed on the reel so that they form a smooth wind with no individual tape strands exposed. A smooth wind offers the advantage of built-in edge protection. A scattered wind will allow individual tape edges to protrude above the others since there is no support for these exposed strands, they are vulnerable to damage.[1]

The textured substrate of back coated tape produces a special compressibility characteristic which is a significant advantage in both handling and wear. The compressible nature of the textured substrate means that the tape will wind more stably but less tightly than standard polyester during normal play mode operations. Rolls of the back treated tape and standard polyester wound on the same machine under the same tensions resulted in the pressure at the hub of the back treated product was 25 to 50% less than that of the standard tape. Thus, if a machine's winding tensions are excessive for

normal tapes, those tapes with the textured substrate will be less likely to be damaged.

Compressibility improves wear characteristics of the tape by minimizing the effects of two potential sources of damage — worked edges and wound-in debris. In addition to cinching or lateral shifting, the tape edges can be damaged by the guide rollers, tape drive or operator. Defective or improperly mounted reels or misaligned transports work the edges of tapes and can ultimately produce stress concentrations capable of permanently distorting the standard polyester tapes when they are wound into roll form. This type of damage generally causes a loss of recorded information and complete failure of the tape. However, in the case of back coated tapes, even though the same stress is applied, the compressible interface dissipates this stress, and the point of permanent distortion is seldom reached. This ability to dissipate stress, and the resultant lower internal pack pressure, also makes it less sensitive to any debris which might be accidentally wound into the pack. Less stress and therefore less distortion is transmitted to adjacent layers, and again the level of permanent distortion is seldom reached.(4)

5.4.2 GUIDING

One of the most serious and more common forms of tape failure is generally categorized as edge damage. Damaged edges can be caused by the transport or the operator. Since the tape can be injured with each revolution of the guide rollers, the result of this series of damaged edges will often appear as a bump on the otherwise smooth surface of the wound tape. A similar situation could result if the reel were not mounted evenly. If the reel pedestal height is improper, or a guide is misaligned, the resulting edge damage may appear as a "lip" on one side of the tape.

Not only will the edge track be lost, but the debris generated from the edge damage could be redeposited back onto the surface of the tape across the entire width. An examination of the edges of a tape that has been damaged in this manner probably would disclose an accumulation of loose polyester fibers and loose oxide.

While this type of damage is serious, it is sometimes difficult to ascertain its cause or even to notice the effect until the damage is severe. Physically inspecting the transport in the area of the guides and heads for an excessive buildup of oxide or backing debris is imperative. Excessive dropouts on an edge track may also indicate that an alignment problem exists. (1)

To meet the requirement of more intimate head to tape contact, tape manufacturers developed ultrasmooth base materials upon which were deposited the uniform oxide coating. The result has been tape that meets performance requirements but creates handling difficulties because of the contact between such smooth surfaces. A textured backing allowed greater wind stability. The problem became one of finding a backing which supplied enough friction between layers to promote pack stability but which at the same time would not emboss or otherwise degrade a recording surface wound next to it.

Frictional characteristics of the treated backing are due to both the surface roughness and the chemical composition of the backing treatment. These frictional properties are more desirable than those of the standard polyester surfaces. Tests show that the result is increased resistance to pack shifting on either a rotational or lateral axis. This prevents cinching and exposed strands, both sources of tape damage.

One of the main problems with conventional polyester backings is that they tend to scratch and chip, creating abraded debris that may clog heads and damage the tape. The textured backing has been found to provide a surface that is significantly more resistant to such abrasion. This means a longer functional life with less dropout activity than conventional polyester during extended usage. Such abrasion resistance also makes the tape more tolerant of slight misalignments in the transport system, resulting in cleaner running tapes with increased life.

Another important feature of the textured product is the fact that the treated substrate is electrically conductive. Since the magnetic surface is also conductive, the possibility of static charges being built up on the tape has been reduced, even over extended and continuous use. Static electricity build-up on the backing has often been a problem with magnetic tape. Static charge helps create noise and, if the charge is large enough, may even cause stick-slip with accompanying speed variations. Even a small amount of static charge can cause problems because of the attraction created for dropout causing dust and debris.

The reduction of static charge build-up reduces the tendency of the tape to attract loose debris. This debris could be oxide ruboff, polyester debris caused by scratching and wear of standard backing, or simply airborne dust and contamination.

Static electricity may attract and hold such debris, and this debris may then be transferred onto the oxide surface as the pack is wound. This could cause dropouts, but the damage might not end there. Such rough debris can cause more scratching, which causes more debris, in a continuing cycle which may be disastrous for the tape. Such debris also has a tendency to abrade the machine heads, greatly reducing their life. The situation multiplies with usage, and the dropouts and output variations can become a serious problem.(4)

5.4.3 HEAD AND TRANSPORT MAINTENANCE

Prior to mounting any magnetic recording tape onto a transport, a complete alignment of all rotating components (such as the capstans, guide rollers, packing rollers, and reel hubs) must be properly aligned to assure tracking of the tape that prevents tape edge damage and improper tape packing. Additional attention must be given to the alignment of the head contact surface to assure its contacting the tape will not effect the tracking. Head protrusion, attack angle, and azimuth must be adjusted for both proper tracking and electro-magnetic performance. The head must also be degaused periodically to assure optimum data recovery.

After each reel of tape is run, the tape drive should be visually inspected to determine if cleaning is necessary. If the transport becomes contaminated with dust or wear products from the tape, complete contamination of an entire roll of tape can easily result.

Contaminants can collect on heads and guides and be dumped along the backing or coating surface of the tape. This contamination will then be wound into the reel under pressure causing it to adhere firmly to the surface. Each one of these deposits will appear as a dropout or group of dropouts the next time the tape is used.

Tape contamination caused by fingerprints can be reduced by remembering not to touch the tape unnecessarily. Frequent cleaning of the tape drive will reduce the chance of spreading contamination from one reel of tape to others in the library. A cotton swab or lint-free pad moistened with Ge nesolve-D (an Allied Chemical trademark), or Freon TF (a DuPont trademark), or similar cleaner is recommended for cleaning all elements of the tape path on the drive. If other types of cleaning agents are used, they should be given time to thoroughly dry before loading the tape. This will prevent damage to the tape should the cleaner have any tendency to attack the magnetic tape.(5)

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